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Disturbance and Recovery of Trampled Montane Grassland and Forests in Montana

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RESEARCH SUMMARY

This study examined the response of five forested vegetation types and one grassland in western Montana to experimental trampling. Changes in vegetation cover, number of species, exposure of mineral soil, and soil penetration resistance were examined, as were the responses of individual species. Trampling treatments ranged from 0 to 1,600 passes per year along trampling lanes and were administered for three successive seasons. Subsequent recovery was followed for 3 years. The most significant conclusions were as follows:

1. Use/impact relationships were nonlinear (asymptotic) for all impact parameters except exposure of mineral soil. Impact increased as trampling intensity increased, rapidly at low levels of trampling and more slowly at high levels. In other words, only at low trampling intensities is amount of impact strongly influenced by differences in amount of use. Above relatively low use thresholds, further increases in use cause little further impact. Unless use levels can be kept well below these thresholds, impacts will be minimized by concentrating use. Use thresholds are estimated for each vegetation type. In the forested vegetation types, use thresholds are exceeded once a site receives 200 to 400 passes per year (I estimate this is roughly comparable to being camped on 1 to 3 nights in 1 year). In the grassland, use thresholds are not reached until sites receive 1,200 passes per year (7 to 8 nights of camping in a year).

2. The *Festuca scabrella-F. idahoensis* (rough fescue-Idaho fescue) grassland was the vegetation type most resistant to vegetation loss. The *Abies lasiocarpa/Xerophyllum tenax* (subalpine fir/beargrass) habitat type was somewhat more resistant to vegetation loss than the other forested types. Differences in vegetation loss among types are most pronounced at trampling intensities of 100 to 200 passes per year, which correspond to a night or two of camping use. Therefore, it can be particularly useful to use these more durable vegetation types where use intensities can be kept to only a night or two of camping per year.

3. The relationship between exposure of mineral soil and trampling intensity is linear. No limit was reached beyond which further use had little additional effect. Moreover, differences between habitat types were most pronounced at the heaviest trampling intensities. Where use intensities are high it makes more sense to choose a site that is resistant to exposure of mineral soil than one with resistant vegetation. Most vegetation will be lost, regardless of its resistance, but some sites can avoid soil exposure (loss of the organic horizons that cover the mineral soil) even after heavy trampling. The most resistant sites are those with thick organic horizons—for example, the *Abies lasiocarpa/Clintonia uniflora* (subalpine fir/queen's cup beadlily) habitat type—that are not located on slopes.

4. The ability of vegetation to recover was high, except where very heavy trampling removed essentially all of the vegetation. Vegetation recovery was greatest in the grassland and the most productive of the forested habitat types, *Abies lasiocarpa/Clintonia uniflora*. Recovery is influenced by both the inherent resilience of constituent species and environmental factors. Recovery of the most severely trampled lanes to the point where visual evidence of disturbance is lacking will require 5 to 10 years, depending on the habitat type. Complete recovery of all species will take much longer.

5. Recovery of a complete litter cover will occur more rapidly, within 5 years on the type most susceptible to mineral soil exposure—the grassland. Recovery of the original depth of litter was not monitored; but it would require a longer recovery period. Recovery from soil compaction was much slower; near-complete recovery will require 5 to 15 years, depending on the habitat type.

6. Deterioration generally reached near-maximum levels after two seasons of trampling. Nevertheless, all of the general conclusions formulated after just one season of trampling (Cole 1985) were corroborated in this longer term study. Other topics addressed include the trampling resistance and resilience (ability to recover) of individual species, implications for management, and suggestions for designing trampling experiments.

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Disturbance and Recovery of Trampled Montane Grassland and Forests in Montana

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INTRODUCTION

Recreational impacts on vegetation and soils present problems for resource managers, particularly those attempting to maintain near-natural conditions in National Parks and wildernesses. In such places, human trampling is the primary recreational activity that inevitably affects vegetation and soil. The effects of most other activities can be minimal if users practice low-impact camping techniques. Research has documented the more obvious effects of trampling and has improved our understanding of how independent variables, such as type, amount, and location of use, influence amount of impact (Cole 1987b; Kuss and Graefe 1985; Liddle 1975a). Studies that carefully monitor the effects of controlled amounts of trampling have been particularly helpful.

Such studies document how rapidly the effects of trampling become obvious. The relative resistance of different environments can be assessed, and it is even possible to predict the effects of various trampling levels on vegetation and soil. By measuring the response of vegetation and soil after trampling is curtailed, recovery rates can be established. Recovery rates are likely to vary with both intensity of trampling and environment. Nevertheless it should be possible to assess the relative resilience of different environments and to predict requisite recovery periods after various amounts of trampling.

Documenting the responses of vegetation and soil to trampling will increase our understanding of these processes and also contribute to more informed management of the backcountry. Study results will improve the ability to predict the consequences of various levels of use. This capability can be used to establish use limits, to decide between dispersing or concentrating use, and to select durable locations for use. Although the results reported here are strictly applicable only to the particular vegetation and soil types that were examined, the study results should provide insights useful in other places.

This paper reports the results of experiments in which various amounts of trampling were applied to six habitat types for three successive summers. Following the cessation of trampling, recovery was monitored for 3 additional years. Objectives of these experiments were to (1) document rates of disturbance and recovery by measuring changes in vegetation cover, number of plant species, organic horizon cover, and soil compaction; (2) determine how disturbance and recovery varies with trampling intensity; and (3) determine how disturbance and recovery varies among habitat types.

STUDY AREA AND METHODS

Five forested plant communities and one grassland were selected for study. Those selected for study were representative of low to middle elevation communities in the Bob Marshall Wilderness, MT. All sites were at elevations of 4,200 to 4,400 feet (1,260 to 1,320 m). At the nearby Seeley Lake weather station, annual precipitation averages 21 inches (536 mm), with a total of 3 inches (75 mm) occurring in summer, July and August, when trampling occurred; January temperatures average 18 °F (–8 °C) and July temperatures average 63 °F (17 °C).

The grassland community, dominated by bunchgrasses, is located on a well-drained, flat upland. It represents the *Festuca scabrella-F. idahoensis* (rough fescue-Idaho fescue) habitat type of Mueggler and Stewart (1980) and will be denoted FESC-FEID hereafter. One forested community is located on a 20- to 25-percent southwest-facing slope. Characterized by medium-sized 1- to 3-foot (0.3- to 1-m) shrubs, it occupies the warmest and driest local environment of the forested communities. It is a member of the *Pseudotsuga menziesii / Symphoricarpos albus* (PSME/SYAL) (Douglas-fir/snowberry) habitat type of Pfister and others (1977). Three forested communities, the *Abies lasiocarpa / Vaccinium caespitosum* (ABLA/VACA) (subalpine fir/dwarf huckleberry), *Abies lasiocarpa / Xerophyllum tenax* (ABLA/XETE) (subalpine fir/beargrass), and *Abies lasiocarpa / Clintonia uniflora-Vaccinium caespitosum* (ABLA/CLUN-VACA) (subalpine fir/queen's cup beadlily-dwarf huckleberry phase) habitat types occupy flat terraces that are subject to frequent frosts. All three have a luxuriant undergrowth dominated by prostrate shrubs. The forested community that appears to be most productive is a member of the *Abies lasiocarpa / Clintonia uniflora* (ABLA/CLUN) (subalpine fir/queen's cup beadlily) habitat type. Soils are deep, soil moisture levels are moderately high, and the frost-free season is relatively long. In contrast to the other forested sites, this community has an overstory of large trees, mostly *Larix occidentalis* (western larch) and *Picea engelmannii* (Engelmann spruce), and an understory dominated by lush, shade-tolerant forbs. Additional information on each type is presented in table 1 and by Cole (1985). All nomenclature follows Hitchcock and Cronquist (1973).

Field Methods

Two replicate sets of experimental trampling lanes were established in each habitat type, except in the ABLA/CLUN and ABLA/CLUN-VACA types, in which only one

Table 1—Site descriptions for each habitat type[1]

Habitat type	Soil type	Mean organic horizon thickness	Mean A and B horizon thickness	Slope	Overstory mean canopy cover and species present	Understory mean total vegetation cover and dominant species
		cm	*cm*	*Pct*		
GRASSLAND TYPE						
Festuca scabrella-F. idahoensis (FESC-FEID)	Typic Haploboroll	3.0	27	0-2	None	94 percent *Festuca scabrella*, *F. idahoensis*, *Lupinus sericeus*, and *Achillea millefolium*
FOREST TYPES						
Pseudotsuga menziesii/ Symphoricarpos albus (PSME/SYAL)	Eutric Glossoboralf	6.0	42	20-25	80 percent *Pseudotsuga menziesii*, *Pinus contorta*, and *Larix occidentalis*	81 percent *Calamagrostis rubescens*, *Berberis repens*, *Arnica cordifolia*, and *Spiraea betulifolia*
Abies lasiocarpa/ Clintonia uniflora (ABLA/CLUN)	Eutric Glossoboralf	11.0	75	0-4	90 percent *Larix occidentalis* and *Picea engelmannii*	93 percent *Thalictrum occidentale*, *Arnica cordifolia*, *Berberis repens*, and *Smilacina stellata*
Abies lasiocarpa/ Clintonia uniflora-Vaccinium caespitosum (ABLA/CLUN-VACA)	Typic Udorthent	6.0	10	0-3	90 percent *Larix occidentalis*, *Pseudotsuga menziesii*, and *Pinus contorta*	92 percent *Linnaea borealis*, *Berberis repens*, *Calamagrostis rubescens*, and *Spiraea betulifolia*
Abies lasiocarpa/ Vaccinium caespitosum (ABLA/VACA)	Andic Dystrochrept	3.5	31	0-7	75 percent *Pinus contorta* and *Larix occidentalis*	90 percent *Vaccinium caespitosum*, mosses, *Xerophyllum tenax*, and *Calamagrostis rubescens*
Abies lasiocarpa/ Xerophyllum tenax (ABLA/XETE)	Andic Dystrochrept	.7	28	0-2	70 percent *Pinus contorta*, *Pseudotsuga menziesii*, *Abies lasiocarpa*, and *Larix occidentalis*	93 percent *Vaccinium scoparium*, mosses, lichens, and *Xerophyllum tenax*

[1] Habitat types are a classification system based on potential climax tree species and indicator understory species (Mueggler and Stewart 1980; Pfister and others 1977). Soil types are based on the 7th Approximation (Soil Survey Staff 1975). Species nomenclature follows Hitchcock and Cronquist (1973). Tree species and understory dominants are listed in order of decreasing mean cover.

set was established. Each set of treatments consisted of 17 lanes, each 1 foot (0.3 m) wide and about 16 feet (5 m) long.

Treatments were randomly assigned to each lane. One treatment was a control and was never trampled. On the other lanes, we varied both the total number of passes per year and the number of days per year when trampling was applied. Whether trampling was concentrated at one time or spread out over the summer had no consistent effect (Cole 1985), however, so all treatments were considered as a simple incremental series. One lane each received 5, 15, 25, 40, 75, 80, 100, 200, 400, 600, 800, 900, 1,200, or 1,600 passes per season and two lanes received 300 passes. Each pass was a one-way walk, at a natural gait, along the lane. The weight of tramplers varied from about 130 to 190 pounds (60 to 90 kg); all wore lug-soled boots.

Trampling treatments were administered between late June and mid-August in 1981, 1982, and 1983. Initial measurements were taken on all lanes in June 1981, prior to any trampling. Followup measurements were taken in June 1982, 1983, and 1984, and in August 1981, 1982, 1983, 1984, 1985, and 1986. The plots in the ABLA/VACA type were disturbed by logging during the period after trampling ceased; consequently, long-term recovery could not be evaluated in this type.

Measurements were taken in four 0.66- by 1.64-foot (2- by 5-dm) subplots placed in the center of each lane, 3.3, 6.5, 9.8, and 13.1 feet (1, 2, 3, and 4 m) from one end of the lane. In each subplot the cover of total ground cover vegetation, exposed mineral soil (without either overlying vegetation or organic material), each vascular plant species, all mosses, and all lichens, was estimated to the nearest percentage if under 10 percent, or in 10-percent coverage classes if between 10 and 100 percent. Soil compaction was measured with a pocket soil penetrometer once in each subplot, below the unconsolidated surface organic litter horizon. For additional information on the layout of the experiments, see Cole (1985).

Data Analysis

Change in vegetation cover was calculated by two different methods. Both are based on the concept of relative cover (Bayfield 1979), which refers to the proportion of the original cover that survives after trampling, corrected by a factor that accounts for changes on the control lanes. The first measure, "vegetation cover," is based on a single estimate of the total cover of vegetation in each subplot. This provides a measure of the proportion of the ground covered by vegetation. It is calculated as follows:

$$\text{Vegetation cover} = \frac{\text{surviving cover on each trampled subplot}}{\text{initial cover on each trampled subplot}} \times \text{cf} \times 100\%$$

$$\text{where cf} = \frac{\text{mean initial cover on control subplots}}{\text{mean surviving cover on control subplots}}$$

and cover is a single estimate of vegetation cover on the subplot.

A more three-dimensional measure of vegetation is provided by what I call "species cover." This relative cover measure is based on the sum of the coverages of all species on the subplot. This sum often exceeded 100 percent because different species form overlapping layers. Species cover provides a more meaningful measure of how much vegetation has been lost as a result of trampling, because in some situations a substantial quantity of vegetation can be lost before vegetation cover declines from 100 percent. Species cover is calculated as follows:

$$\text{Species cover} = \frac{\text{surviving cover on each trampled subplot}}{\text{initial cover on each trampled subplot}} \times \text{cf} \times 100\%$$

$$\text{where cf} = \frac{\text{mean initial cover on control subplots}}{\text{mean surviving cover on control subplots}}$$

and cover is the sum of the percent covers of all vascular species, mosses, and lichens on the subplot.

Species persistence is a measure of vegetation response that reflects changes in the number of species on each subplot. It is calculated as follows:

$$\text{Species persistence} = \frac{\text{number of species on each subplot after trampling}}{\text{initial number of species on each subplot}} \times 100\%$$

Two measures of soil response were used. The first, increase in mineral soil exposure, is concerned with the loss of surface soil organic horizons. It is a measure of the proportion of ground surface on which both vegetation and organic horizons have been lost, exposing bare mineral soil. The formula is:

$$\text{Increase in mineral soil (MS)} = \text{MS (\% cover) after trampling} - \text{initial MS}$$

Soil compaction was assessed by measuring the increase in resistance of the soil to penetration. It was calculated as follows:

$$\text{Increase in penetration resistance (PR)} = \text{PR on each trampled subplot} - \text{mean PR on control subplots}$$

All initial (pretreatment) measurements refer to those taken in mid-June 1981 prior to trampling. Species persistence and increase in mineral soil exposure values were not corrected by a factor related to change on controls, as other measures were. No mineral soil was exposed on controls, so correction was unnecessary. For species persistence it seemed more appropriate to not modify values on the basis of control changes, because even under undisturbed conditions changes in number of species exhibited pronounced local variability. Therefore, changes on controls were not necessarily an accurate reflection of what would have occurred on treated lanes in the absence of trampling. Increases in penetration resistance were not pre- and posttreatment comparisons, as other measures were, because resistance varies with soil moisture and moisture varied greatly between early and late summer and between years. Instead, change was inferred by comparing trampled lanes to controls.

VEGETATION RESPONSES

Deterioration

By August 1983, three successive summers of trampling had reduced vegetation cover on all the habitat types. Cover loss increased as trampling intensity increased (table 2). The relationship between trampling intensity and cover loss was not linear, however; an asymptotic model best describes the relationship. The increase in cover loss with increased trampling intensity is rapid at low levels of trampling but diminishes at higher levels (fig. 1).

Table 2—Species cover[1] after three seasons of trampling

Number of passes per year	Habitat type						All habitat types
	FESC-FEID	ABLA/XETE	ABLA/VACA	PSME/SYAL	ABLA/CLUN-VACA	ABLA/CLUN	
	Percent						
0	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100
5	94^{a}	91^{a}	81^{ab}	86^{ab}	67^{bc}	58^{c}	83
15	87^{a}	85^{a}	76^{ab}	69^{ab}	67^{ab}	59^{b}	76
25	82^{a}	65^{ab}	57^{b}	55^{b}	52^{b}	53^{b}	62
40	85^{a}	65^{b}	52^{bc}	37^{c}	39^{c}	50^{bc}	57
75	91^{a}	45^{b}	37^{b}	32^{b}	38^{b}	27^{b}	47
80	67^{a}	39^{b}	34^{b}	41^{b}	46^{b}	22^{b}	43
100	70^{a}	44^{b}	40^{b}	20^{c}	21^{c}	17^{c}	39
200	69^{a}	31^{b}	7^{c}	5^{c}	5^{c}	6^{c}	23
300	58^{a}	18^{b}	11^{b}	13^{b}	5^{b}	9^{b}	21
400	49^{a}	11^{b}	12^{b}	5^{b}	6^{b}	3^{b}	16
600	35^{a}	15^{b}	10^{b}	9^{b}	0^{b}	4^{b}	14
800	34^{a}	10^{b}	4^{b}	1^{b}	1^{b}	2^{b}	10
900	35^{a}	8^{b}	5^{b}	3^{b}	1^{b}	3^{b}	11
1,200	14^{a}	7^{b}	2^{b}	2^{b}	0^{b}	1^{b}	5
1,600	16^{a}	7^{b}	2^{b}	1^{b}	0^{b}	0^{b}	5
Mean of all treatments	62^{a}	39^{b}	32^{c}	29^{c}	27^{c}	25^{c}	37

[1] Species cover is the proportion of original vegetational cover present after trampling (based on the sum of the coverages of each species), adjusted for changes on controls. Any two cover loss values in the same row followed by the same letter are not significantly different (Duncan's multiple range test, $p = 0.05$).

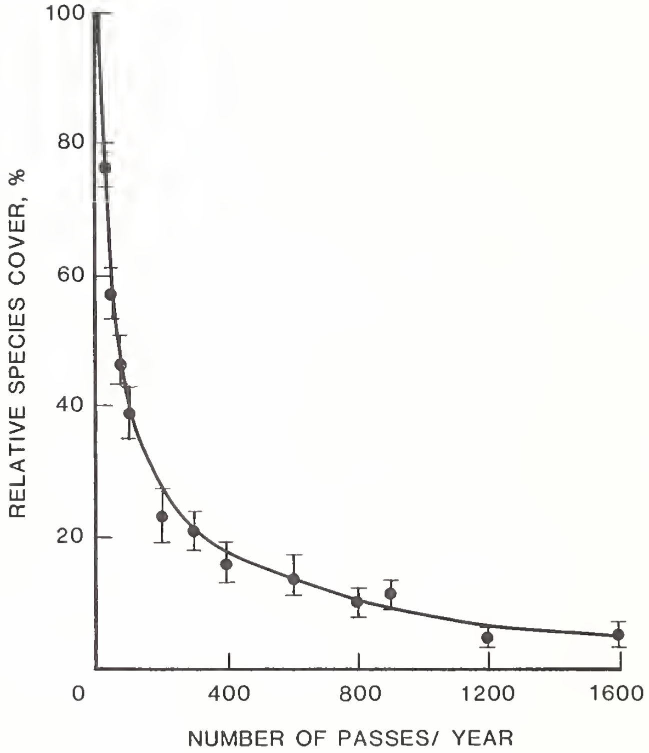

Figure 1—Relationship between trampling intensity and species cover after three seasons of trampling. Species cover is the proportion of original vegetation cover present after trampling (based on the sum of the coverages of each species), adjusted for changes on controls. Data are the mean of all habitat types. Vertical bars are ±1 standard error.

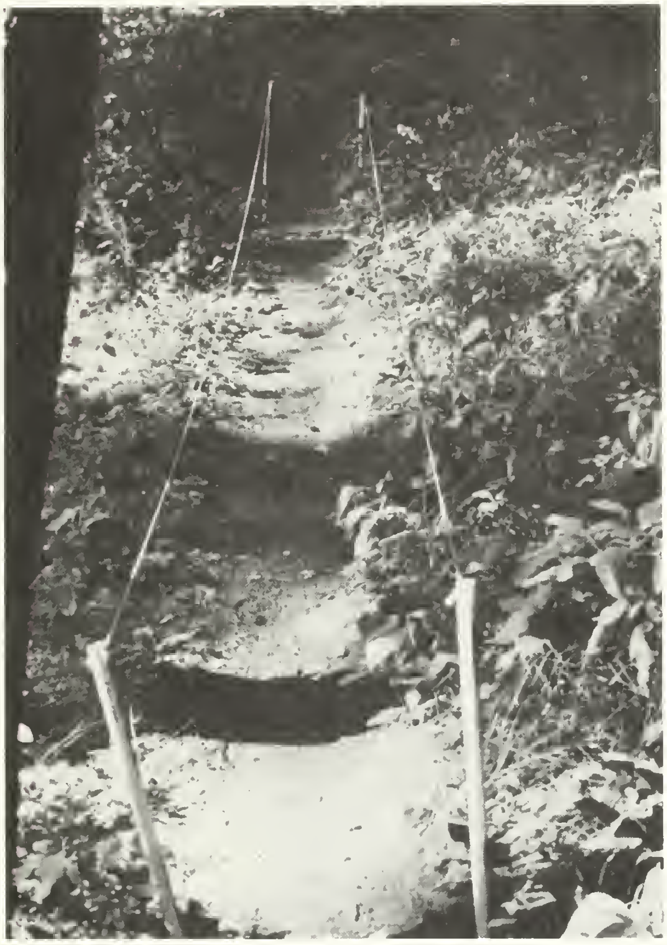

Figure 2—The appearance of the lane with 1,600 passes per year, in the PSME/SYAL habitat type, after the second year of trampling. Vegetational cover is 0 percent; mineral soil exposure is 7 percent.

There were pronounced differences between habitat types, particularly between the grassland and the forests (table 2). In all the forested types, more than 50 percent of the species cover was lost once trampling intensities exceeded 40 passes per year. Only in the most resistant forested type, ABLA/XETE, did more than 15 percent cover survive intensities of more than 100 passes per year (fig. 2). The FESC-FEID grassland was much more resistant; in this type, 50 percent of the cover was lost only where trampling intensity exceeded 300 passes per year.

The general relationship between vegetation cover (based on a single estimate of total vegetation cover) and trampling intensity was also asymptotic. The primary difference between vegetation and species cover (both posttreatment relative cover measures) was that higher levels of vegetation cover survived each trampling intensity. Because loss of one layer of vegetation may not result in a reduction in the areal coverage of vegetation, the volume of vegetation is reduced more rapidly than the areal coverage; therefore, species cover is the more sensitive measure of change. Differences between these two measures were most pronounced on the most lightly trampled lanes. For example, in the ABLA/CLUN type vegetation cover on the 15-pass lane was 89 percent, while species cover was only 59 percent. Thus, with light trampling, considerable vegetation can be lost, despite the fact that total vegetation cover remains near pretreatment levels. With heavy trampling, however, both species and vegetation cover decline dramatically.

The number of passes required to reduce relative vegetation cover to 50 percent has been suggested as an indicator of susceptibility to trampling (Liddle 1975b). In the resistant FESC-FEID grassland, only lanes trampled at least 600 times per year had less than 50 percent vegetation cover. In ABLA/XETE, lanes trampled 300 times per year had less than 50 percent cover. The other four forested types were still more susceptible. The number of passes per year required to reduce this relative measure of cover to 50 percent was 200 in ABLA/VACA, 100 in ABLA/CLUN-VACA and PSME/SYAL, and 75 in ABLA/CLUN.

The proportion of species that survived trampling (species persistence) also declined as trampling intensity increased (table 3). Again the general relationship was asymptotic and the habitat types that were most susceptible to loss of cover were most susceptible to loss of species. Compared with species and vegetation cover, a larger proportion of species survived any given level of trampling. Differences among habitat types were less pronounced than for species and vegetation cover and were most pronounced at higher trampling intensities—600 to 900 passes per year.

Recovery

Considerable recovery occurred on all habitat types after trampling was curtailed (fig. 3). For all types and all trampling intensities, the mean increase in species cover the first year after trampling ceased was 17 percent; mean

Table 3—Species persistence[1] after three seasons of trampling

Number of passes per year	Habitat type						All habitat types
	FESC-FEID	ABLA/XETE	ABLA/CLUN-VACA	ABLA/VACA	ABLA/CLUN	PSME/SYAL	
	Percent						
0	83^{b}	109^{a}	104^{ab}	101^{ab}	102^{ab}	95^{ab}	98
5	90^{a}	108^{a}	97^{a}	91^{a}	81^{a}	92^{a}	98
15	69^{b}	103^{a}	84^{ab}	87^{ab}	94^{ab}	92^{ab}	88
25	77^{b}	106^{a}	83^{ab}	74^{b}	94^{ab}	75^{b}	84
40	78^{bc}	97^{a}	85^{ab}	82^{ab}	85^{ab}	64^{c}	81
75	80^{a}	80^{a}	78^{a}	58^{a}	73^{a}	68^{a}	72
80	77^{a}	78^{a}	81^{a}	66^{ab}	47^{b}	80^{a}	73
100	66^{a}	75^{a}	71^{a}	61^{a}	62^{a}	60^{a}	66
200	84^{a}	61^{ab}	36^{b}	35^{b}	48^{b}	35^{b}	51
300	70^{a}	46^{b}	46^{b}	46^{b}	43^{b}	36^{b}	48
400	55^{a}	32^{b}	35^{b}	29^{b}	11^{b}	26^{b}	33
600	42^{a}	27^{b}	3^{c}	17^{bc}	14^{bc}	26^{b}	24
800	49^{a}	37^{a}	13^{b}	9^{b}	13^{b}	11^{b}	24
900	37^{a}	26^{a}	5^{b}	17^{b}	9^{b}	13^{b}	20
1,200	35^{a}	13^{b}	10^{b}	6^{b}	8^{b}	11^{b}	5
1,600	34^{a}	14^{b}	0^{b}	17^{b}	5^{b}	7^{b}	5
Mean of all treatments	66^{a}	62^{a}	52^{b}	49^{c}	49^{b}	49^{b}	55

[1] Species persistence is the proportion of the original number of species still present after trampling. Any two values in the same row followed by the same letter are not significantly different (Duncan's multiple range test, $p = 0.05$).

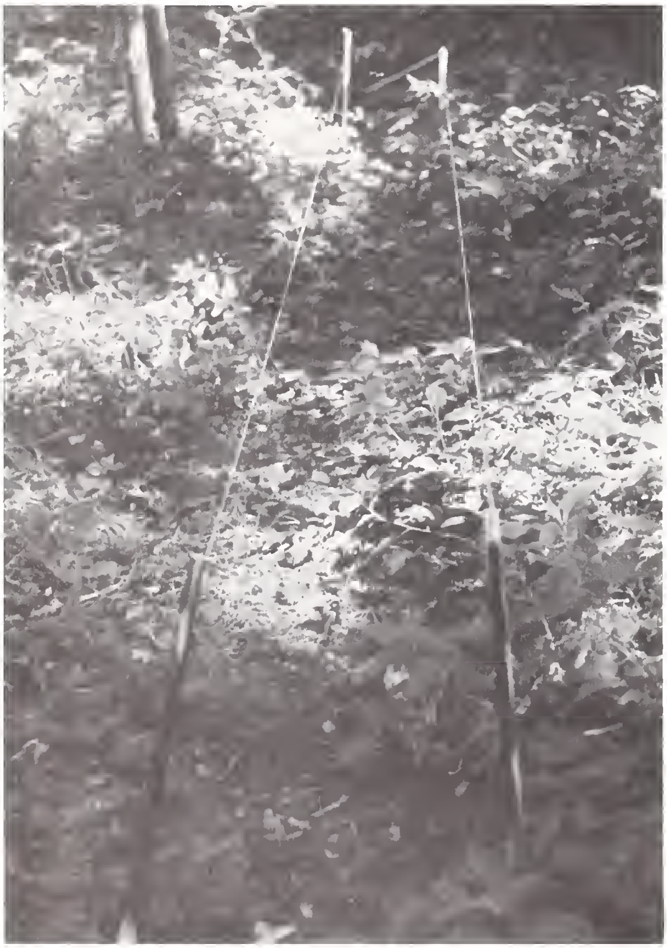

Figure 3—The same lane as in figure 2, 3 years after trampling ceased. Vegetational cover is 29 percent, mostly *Berberis repens*, *Aster conspicuus*, and *Arnica cordifolia*; mineral soil exposure is 0 percent.

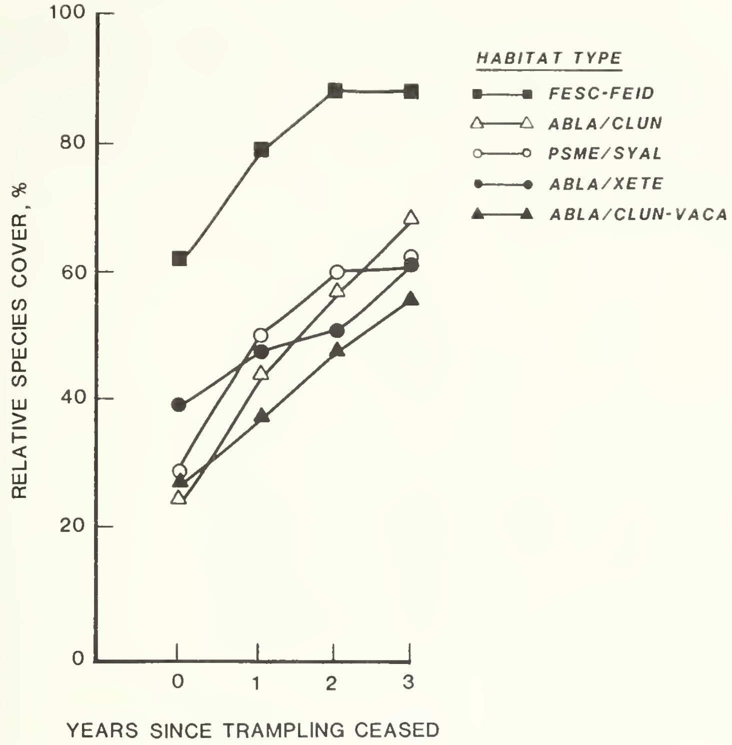

Figure 4—Differences among habitat types in vegetation recovery following the cessation of trampling. Species cover is the proportion of original vegetational cover present at some future date (based on the sum of the coverages of each species), adjusted for changes on controls. Data are the mean of all trampling intensities. All standard errors were between 0.8 and 2.3 percent.

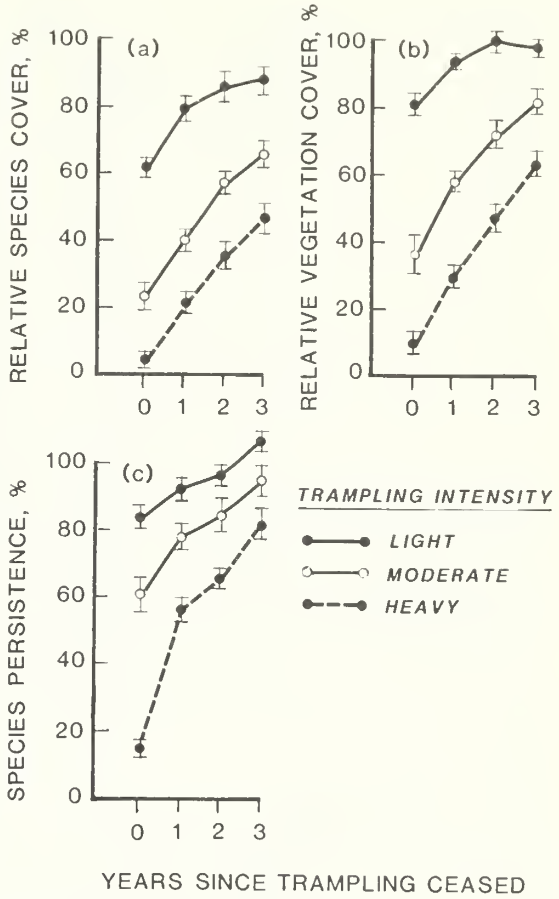

Figure 5—Recovery of (a) species cover, (b) vegetation cover, and (c) species persistence following cessation of trampling at various intensities. See text for definitions. Values for light trampling were median values for lanes with 15, 25, and 40 passes per year, for all habitat types. Values for moderate and heavy trampling were median values for lanes with 100, 200, and 300 passes per year and lanes with 900, 1,200, and 1,600 passes per year, respectively. Vertical bars are ±1 standard error.

increases the 2 following years were 11 and 7 percent. Recovery rates differed among habitat types and with trampling intensity, however (fig. 4).

Figure 5 shows the amount of vegetation recovery each year following curtailment of various levels of trampling. In these graphs and many others in this report, responses to given levels of trampling are expressed as the median of three proximate trampling intensities. For example, light trampling is the median of the lanes with 15, 25, and 40 passes per year. Moderate and heavy trampling are the medians of the lanes with 100, 200, and 300 passes per year and of the lanes with 900, 1,200, and 1,600 passes per year, respectively. This was done because the responses of individual lanes were sometimes affected by an unusual predominance of either resistant or susceptible species, a condition that was impossible to control. Using the median of three trampling lanes resulted in more consistent responses.

As figures 5a and 5b show, recovery rates are constant until species cover approaches 80 percent and vegetation cover approaches 95 percent; above these levels, recovery is less rapid. Recovery of a near-complete vegetation cover occurs rapidly, while development of multilayered vegetation occurs more slowly. Once total cover approaches 100 percent, competition probably slows further increases in vegetation cover.

Recovery of species on the most heavily trampled lanes was most rapid during the first year following the cessation of trampling (fig. 5c). Otherwise, rates were relatively constant, regardless of year since trampling ceased or trampling intensity. Rates did not level off until more than 100 percent of the original species were present. Apparently light trampling can lead to an increase in species richness, a result that provides support for Grime's (1973) hypothesis that maximum species richness occurs at moderate levels of disturbance. Light trampling opens up the cover so new species can colonize, but most of the original species also remain capable of regenerating. Although in many situations an increased species richness might be desirable, from the point of view of preserving natural conditions this represents a human-caused—and therefore undesirable—change.

Despite these general patterns, the response of each habitat type was unique (figs. 6 and 7). In the FESC-FEID grassland, recovery was rapid (tables 4 and 5). Three years after trampling ceased, a path of obviously disturbed vegetation was evident only on the lanes that received

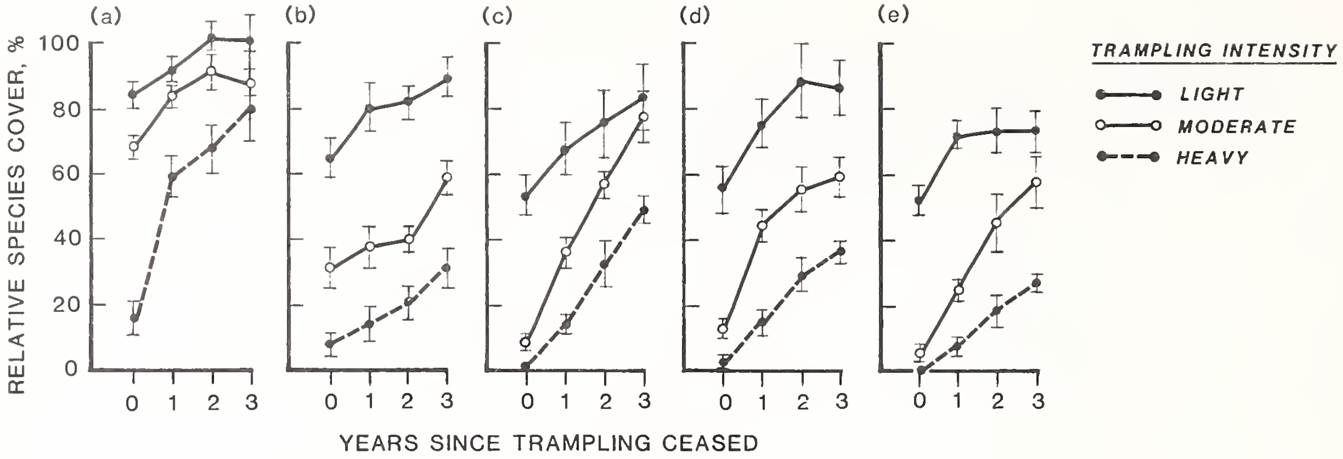

Figure 6—Recovery of species cover following the cessation of trampling. Species cover is the proportion of original vegetational cover present (based on the sum of the coverages of each species), adjusted for changes on controls. Cover values for light trampling were median values for lanes with 15, 25, and 40 passes per year. Cover values for moderate and heavy trampling were median values for lanes with 100, 200, and 300 passes per year and lanes with 900, 1,200, and 1,600 passes per year, respectively. Vertical bars are ±1 standard error. Habitat types are (a) *Festuca scabrella-F. idahoensis,* (b) *Abies lasiocarpa/Xerophyllum tenax,* (c) *Abies lasiocarpa/Clintonia uniflora,* (d) *Pseudotsuga menziesii/ Symphoricarpos albus,* and (e) *Abies lasiocarpa/Clintonia uniflora-Vaccinium caespitosum.*

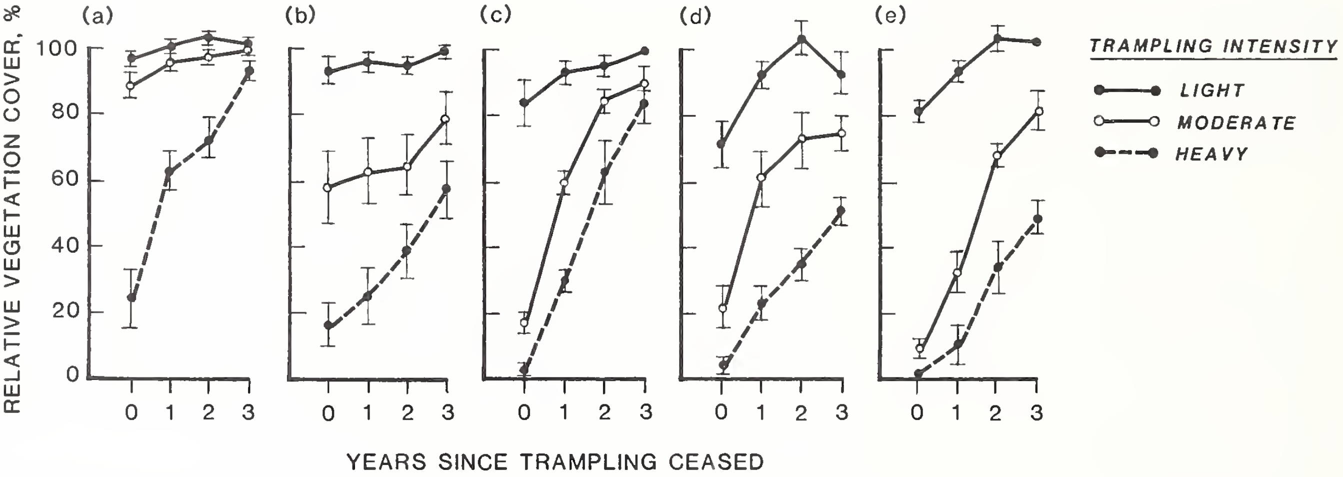

Figure 7—Recovery of vegetation cover following the cessation of trampling. Vegetation cover is the proportion of original cover present (based on a single estimate), adjusted for changes on controls. Cover values for light trampling were median values for lanes with 15, 25, and 40 passes per year. Cover values for moderate and heavy trampling were median values for lanes with 100, 200, and 300 passes per year, and lanes with 900, 1,200, and 1,600 passes per year, respectively. Vertical bars are ±1 standard error. Habitat types are (a) *Festuca scabrella-F. idahoensis,* (b) *Abies lasiocarpa/Xerophyllum tenax,* (c) *Abies lasiocarpa/Clintonia uniflora,* (d) *Pseudotsuga menziesii/Symphoricarpos albus,* and (e) *Abies lasiocarpa/Clintonia uniflora-Vaccinium caespitosum.*

Table 4—Species cover[1] 3 years after trampling ceased

Number of passes per year	Habitat type					All habitat types
	FESC-FEID	ABLA/CLUN	ABLA/XETE	PSME/SYAL	ABLA/CLUN-VACA	
	- - - - - - - - - -	- - - - - - - - - -	- - - - *Percent*	- - - - - - - - - -	- - - - - - - - - -	- - - - - -
0	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100
5	89^{ab}	75^{bc}	102^{a}	101^{a}	63^{c}	90
15	110^{a}	90^{ab}	109^{a}	87^{ab}	77^{b}	98
25	101^{a}	74^{bc}	90^{ab}	67^{c}	73^{bc}	83
40	98^{a}	83^{a}	89^{a}	86^{a}	69^{a}	87
75	99^{a}	73^{b}	79^{b}	66^{b}	73^{b}	79
80	94^{a}	82^{a}	73^{a}	92^{a}	77^{a}	85
100	87^{a}	81^{a}	83^{a}	72^{a}	72^{a}	80
200	87^{a}	42^{b}	59^{b}	48^{b}	43^{b}	60
300	93^{a}	77^{ab}	44^{c}	59^{bc}	58^{bc}	66
400	88^{a}	62^{b}	50^{b}	47^{b}	51^{b}	60
600	71^{a}	76^{a}	49^{ab}	66^{a}	32^{b}	60
800	76^{a}	46^{ab}	33^{b}	33^{b}	42^{ab}	41
900	78^{a}	53^{b}	39^{b}	42^{b}	27^{b}	50
1,200	80^{a}	47^{b}	31^{b}	36^{b}	26^{b}	46
1,600	87^{a}	49^{b}	31^{b}	25^{b}	23^{b}	45
Mean of all treatments	89^{a}	70^{b}	65^{bc}	64^{bc}	57^{c}	70

[1] Species cover is the proportion of original vegetation cover present at some future date (based on the sum of the coverages of each species), adjusted for changes on controls. Any two values in the same row followed by the same letter are not significantly different (Duncan's multiple range test, $p = 0.05$).

Table 5—Species persistence[1] 3 years after trampling ceased

Number of passes per year	Habitat type					All habitat types
	FESC-FEID	ABLA/CLUN	PSME/SYAL	ABLA/CLUN-VACA	ABLA/XETE	
	- - - - - - - - - -	- - - - - - - - - -	- - - - *Percent*	- - - - - - - - - -	- - - - - - - - - -	- - - - - -
0	120	106	107	129	106	113
5	109	105	115	104	105	108
15	88^{a}	123^{b}	100^{a}	107^{ab}	105^{ab}	102
25	108	111	105	103	108	107
40	105	117	114	99	112	110
75	107	105	108	100	110	107
80	110	94	110	108	90	103
100	85	101	104	108	88	95
200	118^{a}	95^{ab}	85^{ab}	92^{ab}	78^{b}	94
300	119^{a}	100^{ab}	99^{b}	86^{b}	81^{b}	98
400	97^{a}	87^{ab}	67^{b}	88^{ab}	65^{b}	79
600	92	97	89	82	81	88
800	88	93	75	69	75	80
900	106^{a}	73^{b}	73^{b}	66^{b}	78^{b}	82
1,200	106^{a}	102^{ab}	83^{bc}	81^{bc}	71^{c}	88
1,600	107^{a}	73^{b}	69^{b}	63^{b}	73^{b}	79
Mean of all treatments	105^{a}	99^{ab}	94^{bc}	92^{bc}	89^{c}	96

[1] Species persistence is the proportion of the original number of species still present at some future date. Any two values in the same row followed by the same letter are not significantly different (Duncan's multiple range test, $p = 0.05$). Rows with no letters have no significant differences.

1,200 and 1,600 passes per year, and the only visual evidence of trampling was abraded clumps of *Festuca scabrella* that had not completely recovered.

Estimates of the period of time required for recovery are of considerable interest. One possible set of criteria for near-complete recovery would be as follows: >95 percent vegetation cover; >90 percent species persistence; >80 percent species cover; and no evident trail. On any lane that met these criteria there would be no visible evidence of disturbance and species cover and composition would be approaching original conditions. Using this definition, recovery of the FESC-FEID type was nearly complete within 1 year on lanes trampled 200 times per year or less, and within 3 years on most lanes trampled 900 times per year or less. Extrapolation of results, which must be interpreted cautiously (recovery rates are not linear), suggests near-complete recovery of the most severely trampled lanes in about 4 years after the cessation of trampling.

Two additional limitations of this study must be kept in mind when interpreting these recovery rates. First, trampling continued for only 3 years, a short period of time compared with how long use has occurred on most recreation sites. Second, narrow trampling lanes were bordered by relatively undisturbed buffer strips that provided sources of seed and vegetative reproduction. Both of these limitations contribute to more rapid recovery than would occur on typical recreation sites.

The ABLA/XETE type recovered steadily but slowly. Cover was low after 3 years of recovery despite the fact that more cover survived trampling on this habitat type than any other forested type (table 4). Three years after trampling had ceased, a path was still evident on lanes trampled as infrequently as 200 times per year. Near-complete recovery occurred in 1 year only on lanes trampled 40 times per year or less; recovery in 3 years usually occurred on lanes trampled 100 times per year or less. Near-complete recovery of the most severely trampled lanes apparently will require about 10 years.

In contrast, ABLA/CLUN recovered rapidly over the 3-year period. ABLA/CLUN was the type most susceptible to vegetation loss, but it was also the most resilient type. It had the least cover immediately after trampling, but 3 years later it had more cover than any of the forested types, and the difference between it and the FESC-FEID grassland declined over the recovery period. Three years after trampling ceased, a path was discernible only on the lanes with 1,200 and 1,600 passes per year. Near-complete recovery did not occur on any lane in 1 year, but occurred within 3 years on lanes trampled 100 times per year or less. Despite the rapid disappearance of visual evidence of impact, species cover values remain depressed. Vegetational cover rapidly recovered, but redevelopment of the original structure of several overlapping layers of vegetation—the sum of coverages of all species exceeded 200 percent on the control—will take much longer. On the most severely trampled lanes, visual evidence of disturbance is likely to disappear within 5 years, but it is likely to take 7 to 8 years for species cover to reach 80 percent.

The other habitat types responded in a manner that was intermediate to the responses of ABLA/XETE and ABLA/CLUN. They were generally less resistant and more resilient than ABLA/XETE, but they were more resistant and less resilient than ABLA/CLUN.

What Determines Amount of Deterioration and Recovery?

Both of the controlled variables, trampling intensity and habitat type, had a substantial influence on amount of deterioration. FESC-FEID is by far the most resistant habitat type, and ABLA/XETE is significantly more resistant than the other forested types. At a trampling intensity of 400 passes per year, for example, FESC-FEID retained 15 times the proportion of cover and five times the proportion of species that ABLA/CLUN did. The ranking of habitat types according to resistance holds at all trampling intensities, although differences were most substantial at trampling intensities of about 100 to 300 passes per year (table 2); differences in resistance to loss of species were most substantial at intensities of 600 to 900 passes per year (table 3).

Differences between habitat types modify the general relationship between deterioration rate and trampling intensity. On each habitat type, cover and number of species declined with increasing trampling intensity before reaching a limit beyond which further increases in trampling intensity cause little additional cover loss. This limit varies greatly between types. It is reached after 1,200 passes per year in FESC-FEID, 400 passes per year in ABLA/XETE, and 200 passes per year in the other types. This limit is significant because it defines the level below which decreases in amount of trampling are likely to have positive benefits—less cover loss—and above which increases in trampling are likely to have little negative effect.

When evaluating recovery, two different measures are needed. First, recovery can be evaluated by comparing conditions following recovery to original conditions. Maximum recovery, using this measure, would occur on the site that most closely approximates original undisturbed conditions. I will refer to this as the **level** of recovery. The problem with relying entirely on this measure is that a resistant site might have a high recovery level without recovering at all. A high recovery level can be simply a result of little impact occurring following treatment. Alternatively, recovery can be evaluated by comparing conditions following recovery to conditions immediately following disturbance. Using this measure, maximum recovery would occur on the site with the greatest difference between conditions immediately following disturbance and conditions following a recovery period. I will refer to this as the **amount** of recovery. This measure is closer to the concept of recovery. The problem with this measure is that resistant sites have a lower potential for recovery because amount of recovery is limited by how much impact occurred. Interpretation of recovery is aided by using both measurements.

The relationship between trampling intensity and recovery is complex. In figure 5a there is an obvious pattern of increasing deterioration (species cover after trampling) and decreasing recovery **level** (species cover 3 years after trampling ceased) with increasing trampling intensity. Those lanes that were trampled most lost the most cover and remained most devegetated 3 years later. This relationship applies across all habitat types, reflecting the strong relationship between trampling intensity and deterioration.

Amount of recovery (the difference in species cover before and after the 3-year recovery period) was not influenced by trampling intensity, however, except at the lowest trampling intensities (< 75 passes per year)—intensities at which amount of recovery was low. This reflects the tendency for amount of recovery to decrease after species cover approaches 80 percent.

When we examine the response of individual habitat types, there are more pronounced differences in amount of recovery related to differences in trampling intensity (fig. 6). In ABLA/XETE, amount of recovery is similar at all trampling intensities; recovery is greatest with heavy trampling in FESC-FEID and recovery is greatest with moderate trampling in ABLA/CLUN, PSME/SYAL, and ABLA/CLUN-VACA. Although the trampling intensity at which recovery is maximized differs among types, the level of deterioration at which recovery is maximized is more consistent. With the exception of ABLA/XETE, amount of recovery is always greatest where 80 to 95 percent of the cover has been lost. Lanes with both more and less deterioration than this recovered less. This leads to the somewhat surprising conclusion that the potential for recovery increases with cover loss, until loss reaches 80 to 95 percent, and then decreases.

In sum, trampling intensity influences deterioration directly, but its effect on recovery is indirect. Within any habitat type, deterioration increases and level of recovery decreases on more heavily trampled lanes. The capacity to recover, however, is more closely related to the amount of surviving vegetation than to trampling intensity. Amount of recovery is greatest where most but not all vegetation has been lost. The ability to recover can be high even after heavy trampling, except where trampling is so severe that all cover is removed. Vegetation retains a high recovery potential, even in the face of increasing levels of trampling, until this threshold is exceeded.

Habitat type directly affects both deterioration and recovery. Data that depict differences among habitat types in deterioration, recovery level, and amount of recovery are plotted in figure 8. This graphic is an extension of one first suggested by Bayfield (1979). The left vertical axis shows species cover 3 years after trampling ceased, providing a measure of recovery level. The bottom axis shows species cover immediately after the third season of trampling, a measure of how much cover has been lost. Amount of recovery is the perpendicular distance of a point from the diagonal line of equal cover both immediately after trampling and after 3 years of recovery. Lines for 0, 20, 40, 60, and 80 percent recovery have been drawn in and are labeled along the right vertical axis. The response of each habitat type to light, moderate, and heavy trampling is indicated. Relative levels of resistance and resilience are summarized in figure 9. The divergent responses of ABLA/CLUN, FESC-FEID, and ABLA/XETE are illustrated in figures 10, 11, and 12.

The relative resistance and resilience of each habitat type, in terms of vegetation cover and species persistence, are similar to that for species cover. As with species cover, recovery of vegetation cover is related more closely to amount of surviving vegetation than to trampling intensity (figs. 5 and 7). The ability to recover remains high, despite increased trampling (amount of recovery actually increases), until trampling is so heavy that surviving cover is only 5 to 10 percent. Beyond this threshold, the ability to recover declines.

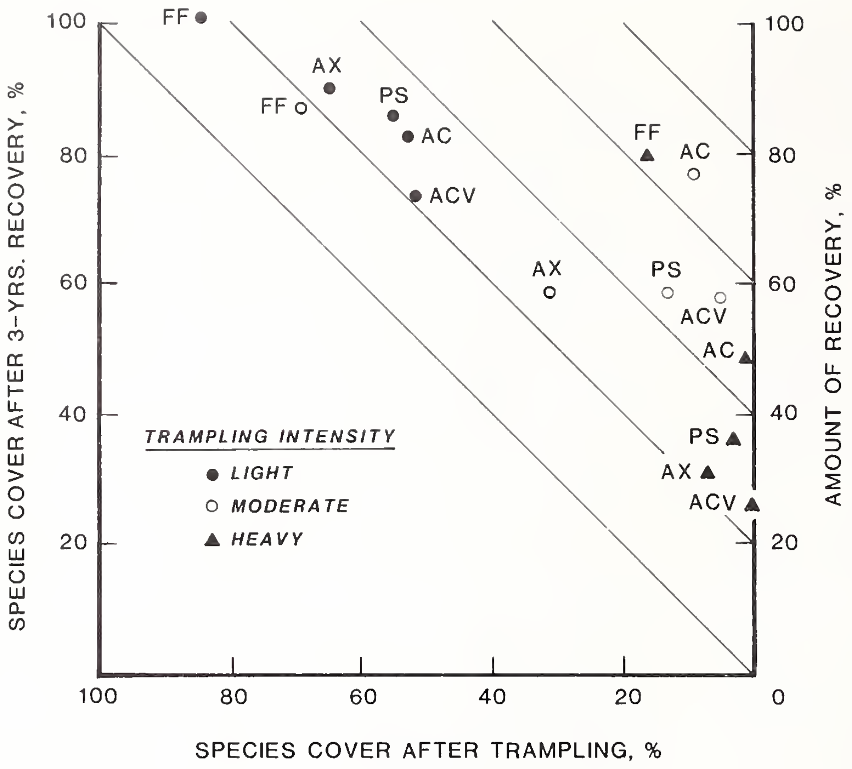

Figure 8—Species cover loss and recovery following light, moderate, and heavy trampling in each habitat type. Species cover is the proportion of original vegetational cover present (based on the sum of the coverages of each species), adjusted for changes on controls. Amount of recovery, the diagonal lines with values along the right axis, is the increase in species cover that occurred during the 3 years following the cessation of trampling. Habitat types are *Festuca scabrella-F. idahoensis* (FF), *Abies lasiocarpa/Xerophyllum tenax* (AX), *Abies lasiocarpa/Clintonia uniflora* (AC), *Pseudotsuga menziesii/Symphoricarpos albus* (PS), and *Abies lasiocarpa/Clintonia uniflora-Vaccinium caespitosum* (ACV). Trampling intensities are light (median of 15, 25, and 40 passes per year), moderate (median of 100, 200, and 300 passes per year), and heavy (median of 900, 1,200, and 1,600 passes per year).

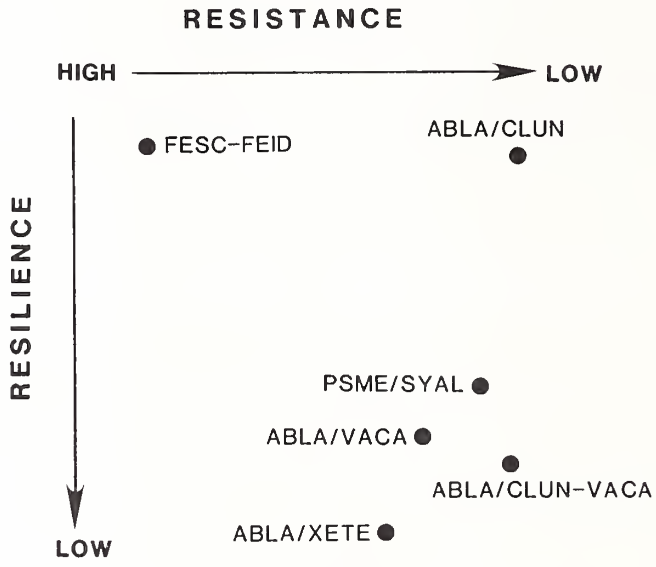

Figure 9—The relative resistance and resilience of each habitat type.

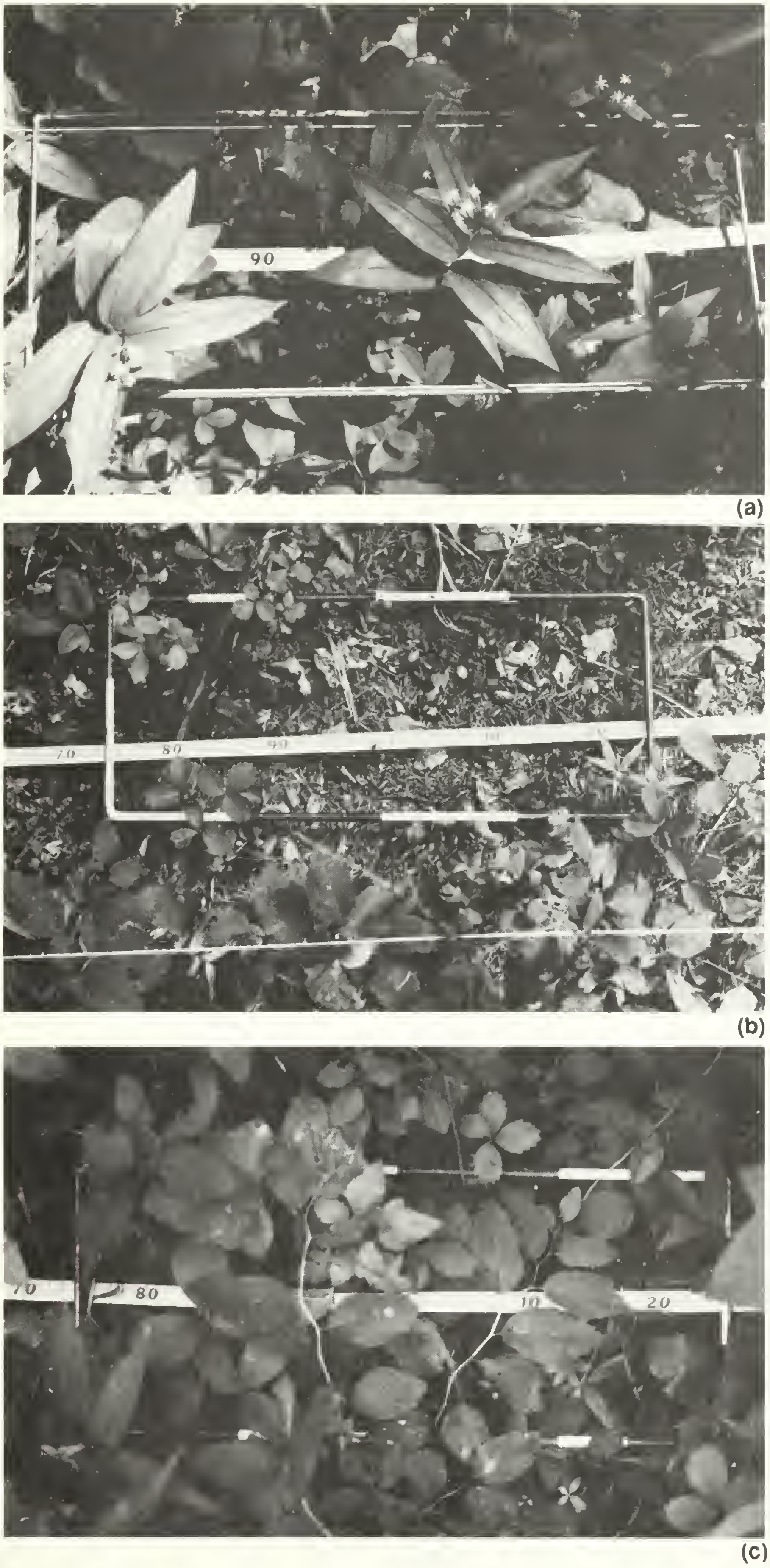

Figure 10—Response of the *Abies lasiocarpa/Clintonia uniflora* habitat type to 300 passes per year. The combined cover of all 11 species was 128 percent before trampling (a). After 3 years of 300 passes per year, only six species survived and cover was 15 percent (b). Three years after trampling ceased, 12 species were found on the subplot and combined cover was 198 percent (c). The most abundant species before trampling (*Smilacina stellata* and *Thalictrum occidentale*) were virtually absent 6 years later, when the most abundant species were *Spiraea betulifolia* and *Arnica latifolia*. This illustrates the low resistance/high resilience response.

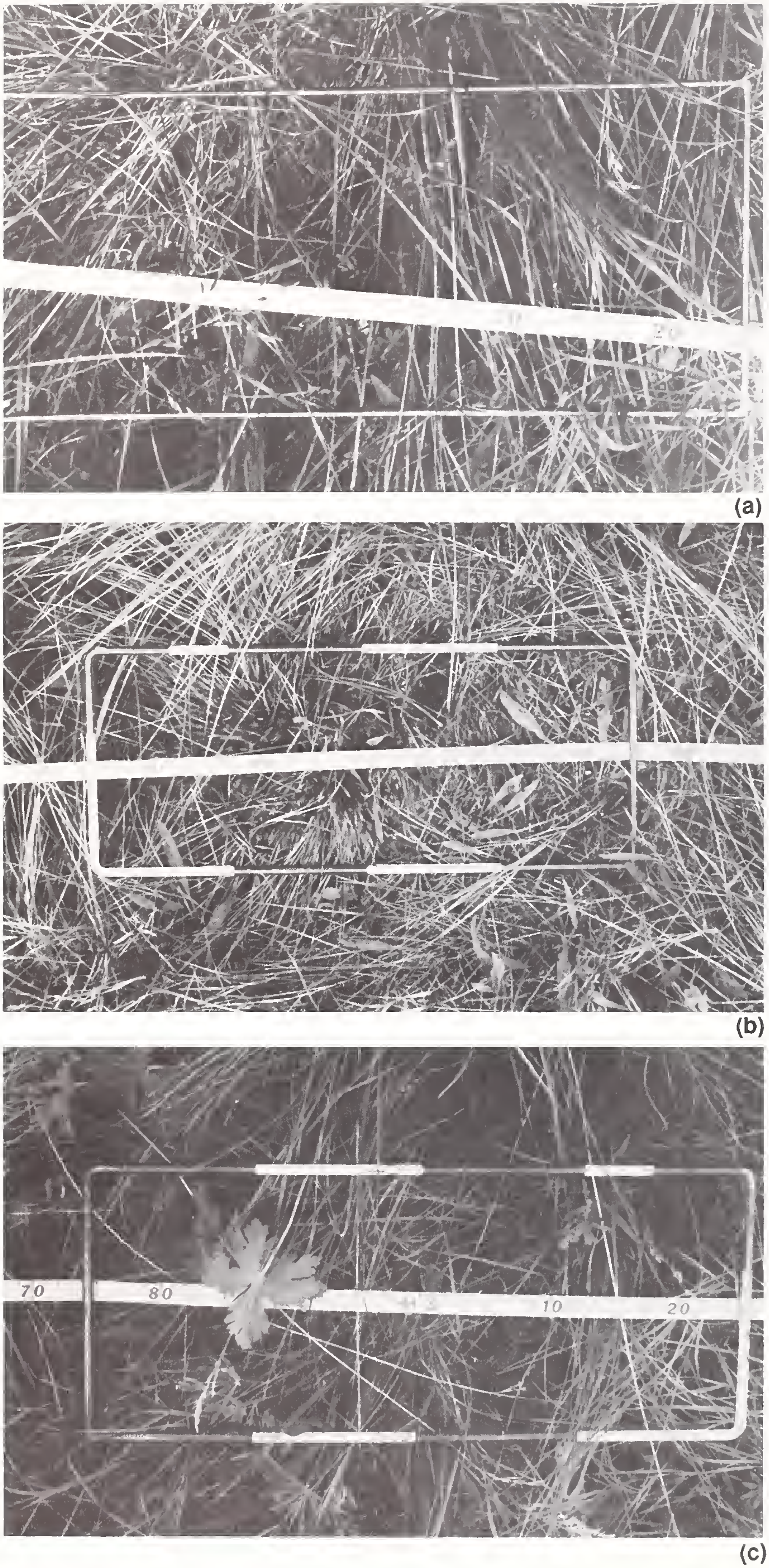

Figure 11—Response of the *Festuca scabrella-F. idahoensis* habitat type to 300 passes per year. Before trampling (a), the combined cover of nine species was 135 percent. After 3 years of 300 passes per year (b) only four species were found, primarily because the forbs had withered by late summer; combined cover was still 85 percent. Three years after trampling ceased (c), eight species had a combined cover of 140 percent. *Festuca scabrella* contributed most of the cover at all observation periods. This illustrates the high resistance/high resilience response.

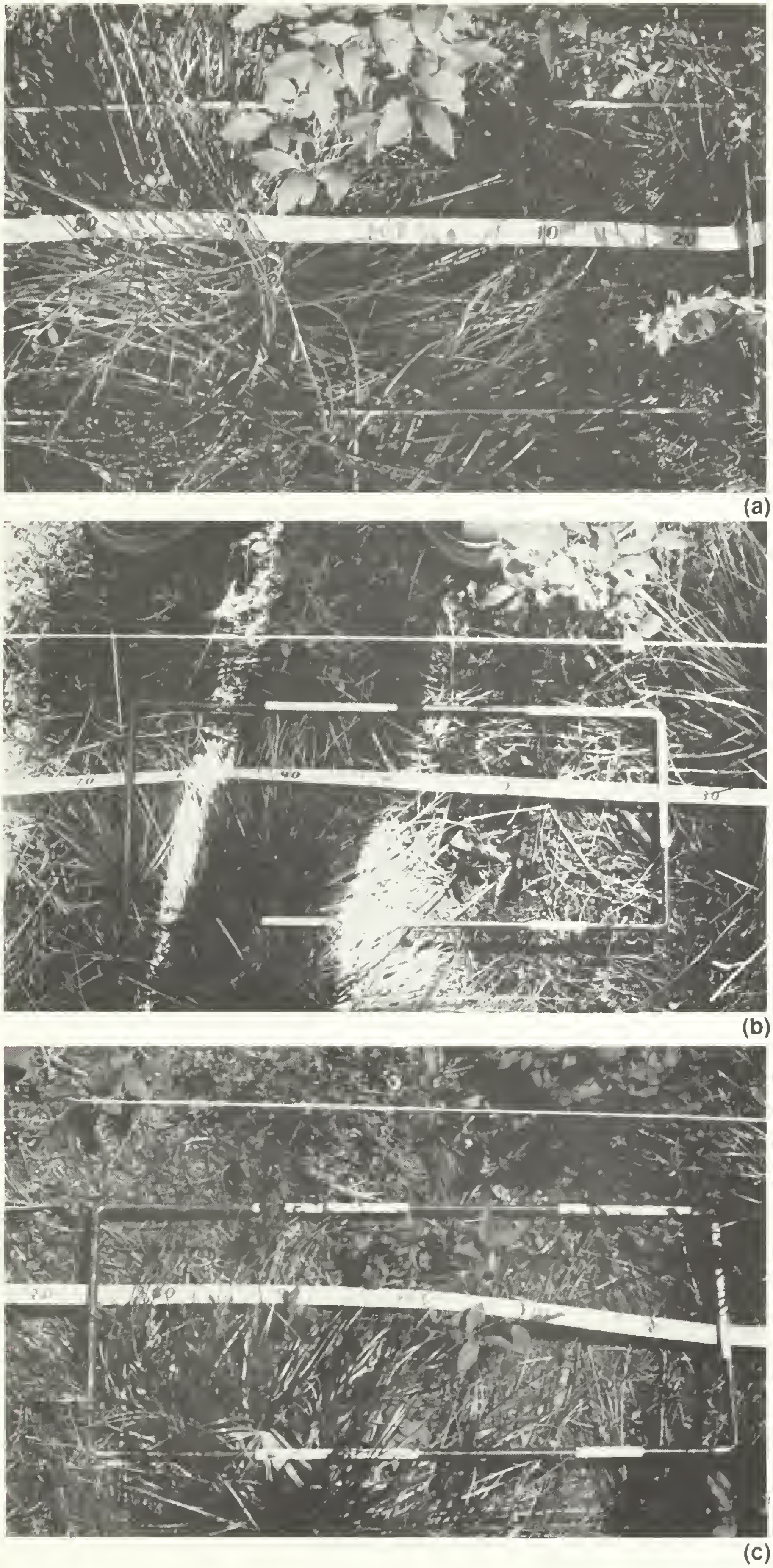

Figure 12—Response of the *Abies lasiocarpa/Xerophyllum tenax* habitat type to 300 passes per year. Before trampling (a), the combined cover of seven species was 155 percent. After 3 years of 300 passes per year (b), only *Xerophyllum tenax* survived (45 percent cover). Three years after trampling ceased (c), six species were present, but they had a combined cover of only 88 percent. Species composition was similar to that before trampling, however. This illustrates the moderately low resistance/low resilience response.

For species persistence, the relationship between trampling intensity and amount of recovery is more direct. Across the range of intensities used in these experiments, amount of recovery increased as trampling intensity increased. No threshold, beyond which increased trampling reduced recovery, was reached. It seems probable that such a threshold does exist; if so it would require much heavier trampling or more than 3 years of trampling.

Liddle (1975b) has advanced the hypothesis that there is a positive correlation between the number of passes required to reduce cover by 50 percent and primary productivity. When only the initial resistance of the vegetation is considered—as in Liddle's hypothesis—the data from this study contradict this notion. The most productive of the forested types, ABLA/CLUN (Pfister and others 1977), is the least resistant to trampling damage. Examination of the results of other trampling experiments that simply measured the initial loss of cover following trampling also reveals little relationship to productivity (Cole 1985). But if the hypothesis is modified to suggest a positive relationship between productivity and the ability to recover from trampling damage, then the data corroborate the hypothesis. ABLA/CLUN is the type that experienced the greatest amount of recovery. This is not surprising because productivity is usually estimated by measuring the difference in biomass between two harvest times.

INDIVIDUAL SPECIES RESPONSES

Deterioration

All species lost cover as trampling intensity increased, but there were pronounced differences in rate of loss. Some species were virtually eliminated after just 1 year of light trampling while others survived 3 years of heavy trampling. Figure 13 shows the response of five species that range from most to least resistant. *Thalictrum occidentale* (western meadowrue), a very sensitive species, was eliminated after 75 passes in just 1 year. *Linnaea borealis* (twinflower), a species that is neither particularly sensitive nor resistant, retained more than 50 percent cover after 3 years of 75 passes per year, but was nearly eliminated at a trampling intensity of 300 passes per year. *Festuca scabrella*, one of the most resistant species, retained more than 60 percent cover after 3 years of 300 passes per year, and more than 20 percent cover survived 3 years of 1,200 passes per year.

Differences in amount of loss resulting from successive years of trampling are also apparent. The most common response (for example, *Calamagrostis rubescens* [pinegrass] and *Linnaea borealis*), is for the first year to cause the most loss, for the second year to cause substantial additional loss, and for the third year to have little effect. For the most resistant species, such as *Festuca scabrella*, the third season of trampling often did cause substantial additional loss, particularly on the most heavily trampled lanes. Such species have a high initial resistance to cover loss, but severe trampling eventually causes pronounced losses. The least resistant species, such as *Thalictrum occidentale*, lose most cover after the first trampling season, and cover may actually increase after additional seasons of trampling, at least on lightly trampled lanes. Although such species have a very low tolerance for trampling, light trampling appears to elicit a response that increases their ability to survive further trampling. Although this type of response has not been reported elsewhere, several authors have reported increases in cover and biomass following low levels of trampling (Liddle 1975a).

Recovery

All species regained at least some lost cover during the 3-year period that followed the cessation of trampling. Most species also regained cover during the 10-month recovery periods that were interspersed with each trampling treatment. The resilience of species—their ability to increase in cover following trampling—varied greatly. Moreover, their ability to recover shortly after trampling ceased (for example, in the period between trampling

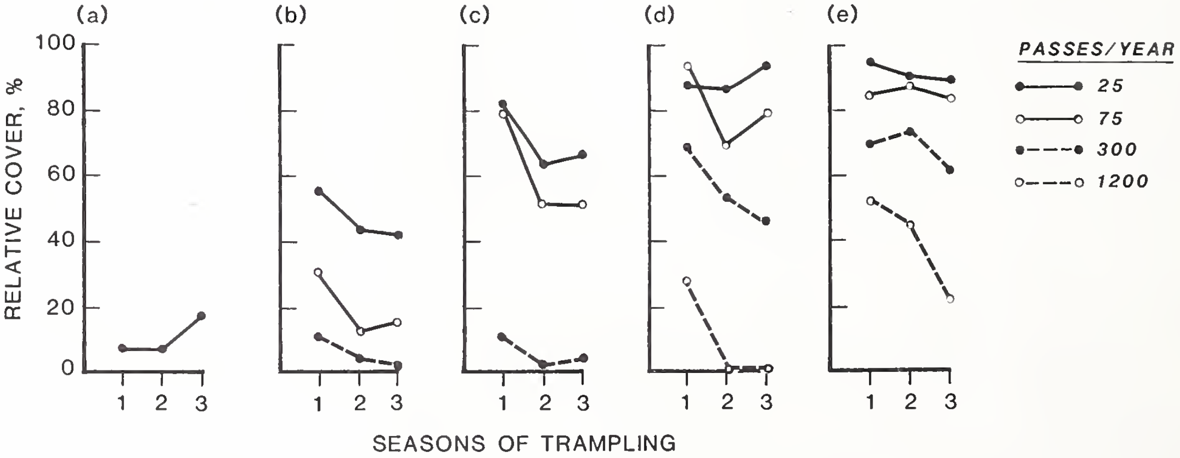

Figure 13—Loss of relative cover of (a) *Thalictrum occidentale*, (b) *Calamagrostis rubescens*, (c) *Linnaea borealis*, (d) mosses, and (e) *Festuca scabrella* over three seasons of trampling at various intensities. Relative cover, always 100 percent before treatment, is the proportion of the original cover still present after trampling, adjusted for changes on controls.

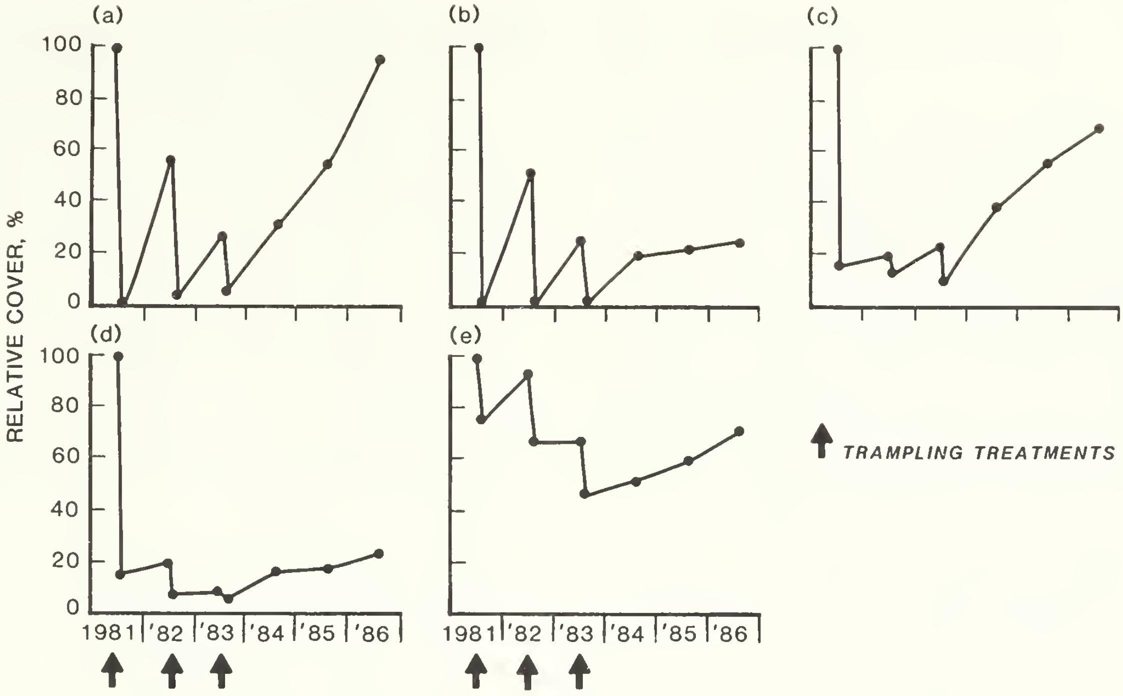

Figure 14—Deterioration and recovery of (a) *Arnica latifolia*, (b) *Thalictrum occidentale*, (c) *Berberis repens*, (d) *Fragaria virginiana*, and (e) *Xerophyllum tenax* following trampling at an intensity of 300 passes per year. Relative cover is the proportion of the original vegetation still present at some later date, adjusted for changes on controls.

seasons) was often different from their ability to recover over a longer period (for example, during the 3-year recovery period). Thus, it seems appropriate to distinguish between short- and long-term resilience.

Figure 14 shows five different responses. *Arnica latifolia* (mountain arnica) was virtually eliminated by 300 passes, but 10 months later it had regained over 50 percent of its original cover. This high short-term resilience diminished some after the second trampling season. But long-term recovery remained relatively high; cover 3 years after trampling ceased was 92 percent of original cover. *Thalictrum occidentale* also has high short-term resilience, but its long-term resilience is low. Successive years of trampling diminish its resilience substantially. *Berberis repens* (creeping Oregongrape) has low short-term resilience, but once trampling was eliminated for a long period of time, it recovered steadily. Long-term resilience is relatively high. *Fragaria virginiana* (blueleaf strawberry) is a species in which both short- and long-term resilience is low. The resilience of resistant species, such as *Xerophyllum tenax*, is more difficult to evaluate because they retain most of their cover except when severely trampled.

Classification of Species

With the exceptions of *Festuca scabrella* and *Xerophyllum tenax*, all species were nearly eliminated at some trampling intensity over the 3-year period. The lowest trampling intensity at which this occurred was used to categorize species according to resistance (table 6). My formal definition of "near-elimination" was a reduction in frequency of occurrence in subplots to 50 percent of pretrampling frequency and a reduction in relative species cover to 20 percent. If near-elimination occurred at trampling intensities of 40 passes per year or less, species were termed very sensitive; species that did not experience near-elimination except at intensities of 1,200 passes per year or more were termed very resistant. Intermediate terms and trampling intensities were sensitive (75 to 100 passes per year), neither resistant nor sensitive (200 to 400 passes per year), and resistant (600 to 900 passes per year).

Species were categorized according to resilience on the basis of how they recovered from moderate trampling. Short-term resilience was based on the increase in cover between the end of the first trampling season and the start of the second trampling season. Increase was the median difference in cover for the 200-, 300-, and 400-pass lanes between August 1981 and June 1982. If this median increase was greater than 30 percent, short-term resilience was high (table 6). Resilience was moderate if the increase was 10 to 30 percent and low if the increase was less than 10 percent. Fewer classes were used than for resistance because responses were more variable and, therefore, more difficult to categorize. Long-term resilience was classified in exactly the same manner, except that the measurements compared were those taken in August 1983 (immediately after three seasons of trampling) and in July 1986 (after 3 years of recovery).

This classification can be used to predict the response of these species to trampling disturbance. Habitat types with large proportions of resistant or resilient species are likely

Table 6—Classification of the more abundant species according to their resistance and resilience

Species	Resistance[1]	Resilience	
		Short-term	Long-term[3]
SHRUBS AND SUBSHRUBS			
Amelanchier alnifolia (western serviceberry)	M	L	M
Acrostaphylos uva-ursi (kinnikinnick)	M	L	L
Berberis repens (creeping Oregongrape)	M	L	M-H
Chimaphila umbellata (prince's-pine)	L	L	L
Linnaea borealis (twinflower)	M	L	H
Pachistima myrsinites (mountain-lover)	M	L	L-M
Rosa gymnocarpa (baldhip rose)	M	L-M	M
Rubus parviflorus (thimbleberry)	L	H	H
Spiraea betulifolia (shiny-leaf spirea)	L	M-H	M-H
Symphoricarpos albus (snowberry)	L	M-H	H
Vaccinium caespitosum (dwarf huckleberry)	M	M	-
Vaccinium globulare (globe huckleberry)	L	L	M
Vaccinium scoparium (grouse whortleberrry)	M	L	M
GRAMINOIDS			
Calamagrostis rubescens (pinegrass)	L	L-M	L
Carex concinnoides (northwest sedge)	M	L	L
Carex geyeri (elk sedge)	H	L	M
Festuca scabrella (rough fescue)*	VH	L	M
FORBS			
Achillea millefolium (common yarrow)	M	M	M
Adenocaulon bicolor (pathfinder)	VL	H	H
Antennaria racemosa (raceme pussy-toes)	M	L	L
Arenaria congesta (capitate sandwort)*	VH	M	M
Arnica cordifolia/A. latifolia (heart-leaf/mountain arnica)	L	H	H
Aster conspicuus (showy aster)	VL	H	H
Aster foliaceus (leafy aster)	L	L	H
Chrysopsis villosa (hairy golden-aster)	H	M	M
Clintonia uniflora (queen's cup beadlily)	L	H	M
Epilobium angustifolium (fireweed)	VL	H	H
Eriogonum umbellatum (sulfurflower)	M	L	M
Fragaria virginiana (blueleaf strawberry)	L	L-M	L-M
Galium triflorum (fragrant bedstraw)	L	L	H
Geranium viscosissimum (sticky purple geranium)	L	H	H
Goodyera oblongifolia (western rattlesnake-plantain)	M	L	L
Hedysarum occidentale (western sweetvetch)	VL	H	-
Hieracium albiflorum (white flowered hawkweed)	M	L	L
Lupinus argenteus (silvery-lupine)	VL	M	-
Lupinus sericeus (silky lupine)	VL	H	H
Melampyrum lineare (narrow-leaved cow-wheat)	VL	H	H
Osmorhiza chilensis (mountain sweet-root)	L	H	H
Penstemon confertus/P. procerus (yellow/small-flowered beardtongue)	M	H	M
Potentilla gracilis (slender cinquefoil)	M	H	H
Smilacina stellata (starry false Solomon's seal)	L	H	M
Solidago missouriensis (Missouri goldenrod)	H	M	M
Thalictrum occidentale (western meadowrue)	VL	H	M
Viola orbiculata (round-leaved violet)	M	M	M
Xerophyllum tenax (beargrass)*	VH	L	M
TREE SEEDLINGS	L	L	L
MOSSES*	H	L-M	M
LICHENS	L	M	L

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[1] Resistance was based on the number of passes per year required to reduce frequency of occurrence in subplots to 50 percent of pretrampling frequency and relative cover to 20 percent. Classes are: very high (VH) (≥1,200 passes per year); high (H) (600-900 passes per year); moderate (M) (200-400 passes per year); low (L) (75-100 passes per year); very low (VL) (≤40 passes per year).

[2] Short-term resilience was based on the increase in relative cover between the end of the first trampling season (August 1982) and the start of the second trampling season (June 1982). The median increase on the 200-, 300-, and 400-pass lanes was used as an indicator of recovery following moderate trampling. Classes are: high (H) (>30 percent increase); moderate (M) (10-30 percent increase); low (L) (<10 percent increase).

[3] Long-term resilience was based on the increase in relative cover between the end of the last trampling season (August 1983) and the end of the recovery period 3 years later (July 1986). The median of the 200-, 300-, and 400-pass lanes was used. The response of species with an asterisk (*) was evaluated on more heavily trampled lanes so that response following severe cover loss could be evaluated.

to tolerate trampling well or recover quickly from trampling damage. Generally, we can predict that intermittent light trampling will be least damaging where species are resistant. Intermittent heavy trampling will be least damaging where species have high short-term resilience; prolonged trampling, particularly if it is heavy, will be least damaging where long-term resistance is high. A more definitive picture of how species respond to different intensities and frequencies of disturbance can be gained by integrating resistance and resilience.

Integration of Resistance and Resilience

For the 18 most widely distributed species, it is possible to integrate both resistance and long-term resilience using the modification of Bayfield's (1979) ordination (fig. 15). This illustrates the ability of each species to resist and recover from the impact of being trampled 300 times per year for 3 years. Three clusters of response are obvious. In the lower right corner of the graph are sensitive species with low resilience: *Chimaphila umbellata* (prince's-pine), *Vaccinium globulare* (globe huckleberry), *Calamagrostis rubescens, Thalictrum occidentale, Smilacina stellata* (starry false Solomon's seal), *Vaccinium scoparium* (grouse whortleberry), and lichens. In the upper right corner are species of intermediate resistance and high resilience: *Linnaea borealis*, *Arnica cordifolia* (heart-leaf arnica), *Spiraea betulifolia* (shiny-leaf spirea), *Berberis repens*, and *Achillea millefolium* (common yarrow). Resistant species that do not recover much—in the upper left and center of the graph—are *Arenaria congesta* (capitate sandwort),

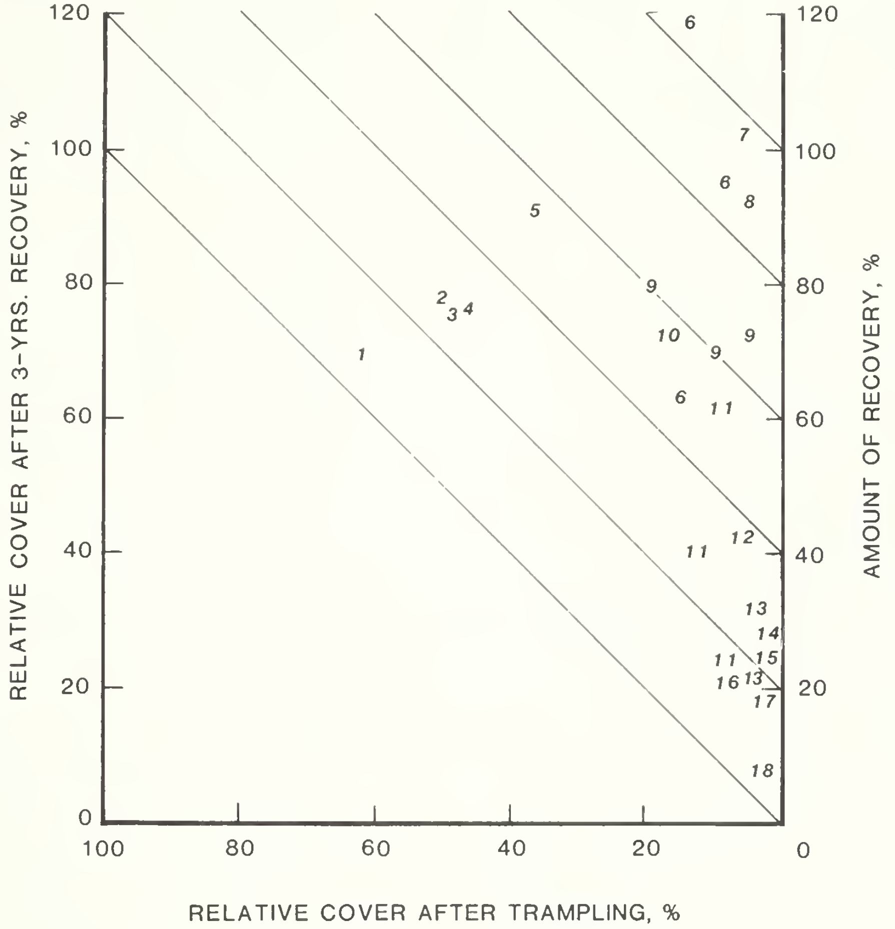

Figure 15—Cover loss and recovery of common species following moderate trampling (300 passes per year for 3 years). Relative cover is the proportion of original cover present, adjusted for changes on controls. Amount of recovery, the diagonal lines with values along the right axis, is the increase in cover that occurred during the 3 years following the cessation of trampling. Species are: (1) *Festuca scabrella*, (2) *Arenaria congesta*, (3) *Xerophyllum tenax*, (4) mosses, (5) *Solidago missouriensis*, (6) *Spiraea betulifolia*, (7) *Linnaea borealis*, (8) *Arnica cordifolia*, (9) *Berberis repens*, (10) *Achillea millefolium*, (11) *Fragaria virginiana*, (12) *Vaccinium scoparium*, (13) *Calamagrostis rubescens*, (14) *Smilacina stellata*, (15) *Thalictrum occidentale*, (16) lichens, (17) *Vaccinium globulare*, and (18) *Chimaphila umbellata*.

Festuca scabrella, *Xerophyllum tenax*, and mosses. The response of these species following the cessation of heavy trampling indicates that *Festuca scabrella* and *Arenaria congesta* are quite resilient, while the resilience of *Xerophyllum tenax* and mosses is less. *Solidago missouriensis* (Missouri goldenrod) is moderately resistant and resilient.

Three species were abundant in several different habitat types. In each of three habitat types, *Berberis repens* was neither resistant nor sensitive (5 to 20 percent cover survived 300 passes per year); resilience was moderately high in each type (cover increased 60 to 70 percent after trampling ceased). The resistance of *Spiraea betulifolia* was also similar in each of three habitat types (8 to 15 percent survival). Resilience, however, was much higher in the ABLA/CLUN type (cover increased more than 100 percent) and in PSME/SYAL (85 percent increase) than in ABLA/XETE (50 percent increase). The resistance of *Fragaria virginiana* was also similar in three types (7 to 12 percent survival), while resilience varied greatly. Again, resilience was greatest in ABLA/CLUN (50 percent increase) and less in ABLA/CLUN-VACA (30 percent increase) and PSME/SYAL (20 percent increase). These results indicate that resilience can vary greatly within the same species while resistance does not. This corroborates the hypothesis that resistance is determined primarily by plant characteristics, while resilience is strongly influenced by habitat factors such as soil fertility, moisture regime, and length of the growing season (Cole 1987b).

Figure 16 provides examples of four basic types of response: low resistance and resilience (lichens), low resistance and high resilience (*Arnica cordifolia*), high resistance and low resilience (*Xerophyllum tenax*), and high resistance and resilience (*Arenaria congesta*). Differences in resistance among these species are greatest at moderate trampling intensities of 200 to 800 passes per year. Differences in resilience are most pronounced at the highest intensities.

Resistance and resilience are also integrated in the concept of **recovery level**. Recovery level, as defined earlier, is a measure of cover following both a period of deterioration and a period of recovery. Recovery level can be high for resistant species with low resilience, such as *Xerophyllum tenax*, and sensitive species with high resilience, such as *Arnica cordifolia*, as well as for resistant and resilient species, such as *Arenaria congesta* (fig. 16). In fact, many of the species with the highest relative cover 3 years after trampling ceased were sensitive species that were eliminated by moderate and heavy trampling.

Of particular interest is the level of trampling each species can endure and still recover to a condition close to

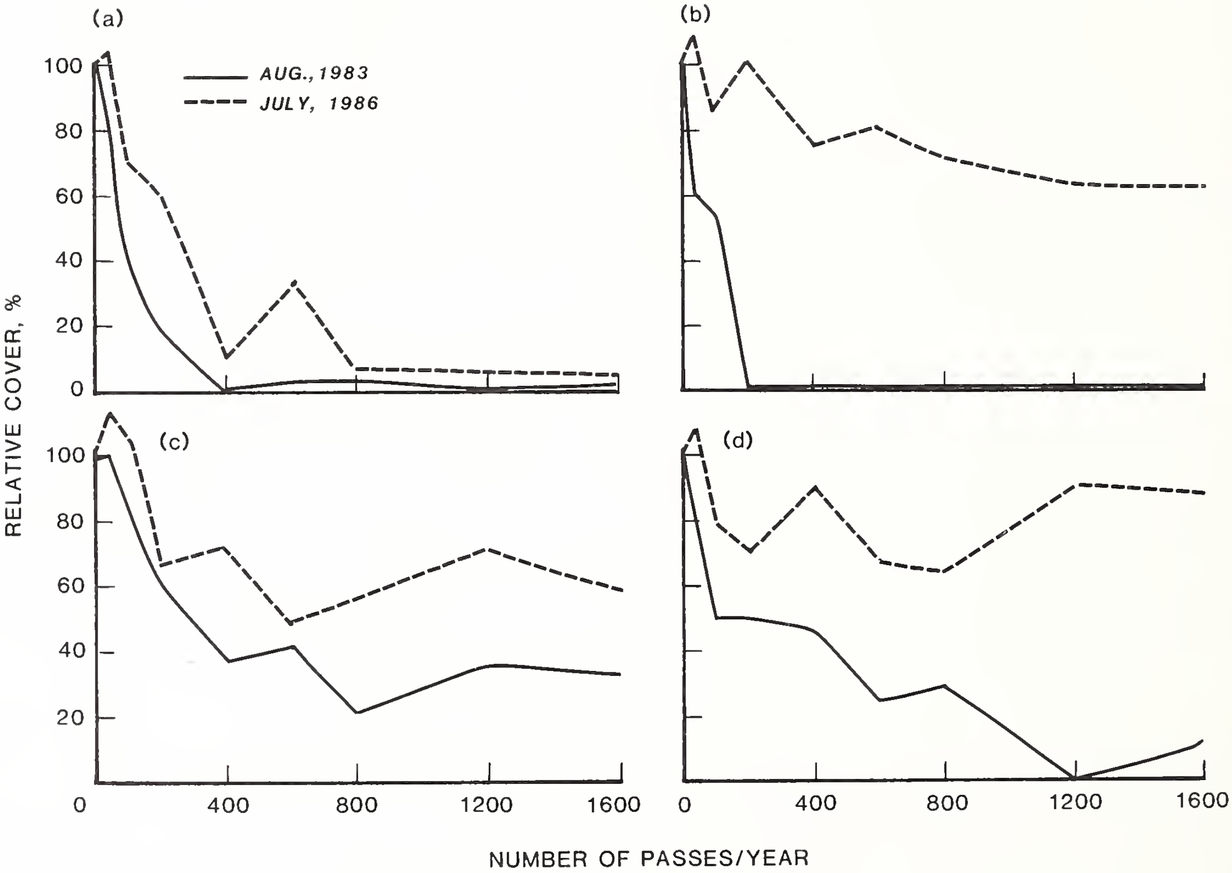

Figure 16—Relationship between trampling intensity and relative cover after three seasons of trampling (August 1983) and 3 years of recovery (July 1986) for (a) lichens, (b) *Arnica cordifolia*, (c) *Xerophyllum tenax*, and (d) *Arenaria congesta*. Relative cover is the proportion of original cover present, adjusted for changes on controls.

what existed prior to trampling. Using relative cover of at least 80 percent as a definition of near-complete recovery, the maximum number of passes per year each species tolerated and still nearly recovered was determined. Both short-term recovery—between August 1981 and June 1982 (after one season of trampling and 10 months of recovery)—and long-term recovery—between August 1983 and July 1986 (after 3 years of trampling and 3 years of recovery)—were evaluated (table 7).

Managers can use this table when attempting to control use levels such that these species are not permanently damaged. The column for short-term recovery is most appropriate when considering the effects of intermittent trampling, such as cross-country hiking or highly dispersed camping in areas without well-developed campsites. Long-term recovery is most appropriate for considering how species are likely to recover after a period of prolonged use.

What Determines Amount of Deterioration and Recovery?

Amount of deterioration was strongly influenced by trampling intensity. All species declined in cover as trampling intensity increased. Habitat type had little influence on loss of cover, however. Those species that were found in several different types tended to experience similar losses in each type.

This finding runs counter to the conclusion of some researchers that the resistance of species is strongly influenced by environmental factors such as soil conditions, topography, and other vegetation on the site (Kuss and Graefe 1985; Price 1985). Some of this discrepancy might be explained by the tendency to confuse species resistance with habitat resistance. Wet soils, for example, are more seriously compacted by trampling than drier soils, and the species that occupy such sites are usually more susceptible than those that occupy dry sites (Strand 1979; Willard and Marr 1970). But they usually are very different species. We have very little data to evaluate whether an individual species is more sensitive to trampling when growing in wet or dry soils.

One experimental study that did provide some data on the response of the same species in different environments was Holmes and Dobson's (1976) study of subalpine meadows in Yosemite National Park. They found that resistance tended to be low in pure communities as opposed to mixed communities, in dry and sandy soils, and on steeply sloping sites. Apparently layered communities offer more protection to plants. Tall plants can shelter smaller plants and ground-level plants cushion taller plants when they are pressed against the ground surface. Also, dry and sandy soils can be easily gouged and displaced by boots, either burying or uprooting plants. Displacement is aggravated on steeper slopes. Even these generalizations were based on the responses of only a few species in an unreplicated experiment.

In the study reported here, it was obvious that the persistence of resistant clumps of *Festuca scabrella* protected many of the other species growing in that habitat type. In some cases only underground plant parts were protected; this is reflected in the trampling intensities species can tolerate and still recover (table 7). For example, two morphologically similar species, *Lupinus argenteus* (silvery lupine), which was on the ABLA/VACA plots, and *Lupinus sericeus* (silky lupine), which was on the FESC-FEID plots, were eliminated by low levels of trampling. In neither case were the aerial parts of the plants protected from damage. But *L. argenteus* could recover only from light trampling, while *L. sericeus* recovered from very heavy trampling. A likely explanation for this result is that the remnant *Festuca scabrella* clumps absorb much of the trampling impact and protect the underground perennating organs of *L. sericeus*. In the absence of *Festuca scabrella* clumps, perhaps *Lupinus sericeus* would have been so damaged by heavy trampling that it too would not have recovered.

The aerial parts of low-growing plants may also be protected from trampling damage. Three highly resistant species on the FESC-FEID plots, *Arenaria congesta*, *Chrysopsis villosa* (hairy golden-aster), and *Solidago missouriensis*, have characteristics that make them resistant to trampling (these will be discussed in more detail later). But their survival rates would probably have been much lower if they were unable to grow underneath persistent grass clumps. In fact, their survival rates were often considerably reduced on subplots that did not have much *Festuca scabrella* cover.

It was also obvious that wherever the microtopography was hummocky, trampling was concentrated on the tops of hummocks and plants that grew there were particularly vulnerable, while those growing in depressions were largely spared. Often such differences in microtopography are reflected in differences in species composition. In Olympic National Park, for example, Bell and Bliss (1973) report more damage to *Lupinus lepidus* (prairie lupine), which grows on the tops of hummocks, than to *Carex phaeocephala* (dunhead sedge), which grows on hummock sides. In this case, topography makes it more likely that *L. lepidus* will be damaged than *C. phaeocephala* because hummocks are more likely to be trampled and *L. lepidus* is more likely to grow on hummocks. But the hummocks do not alter the inherent resistance of these two species to trampling.

In sum, we have insufficient data to make generalizations about the importance of habitat factors in modifying the resistance of individual species; statements to the contrary should be treated as working hypotheses. In this study, habitat differences had little effect. There are theoretical grounds for believing that substantial differences in environmental factors, such as light intensity or soil moisture, might affect the resistance of a given plant species to trampling. But where such differences exist, they are usually reflected in dramatic differences in species composition. While environmental factors may exert some influence on the resistance of individual species—further research might allow us to quantify this better—their primary influence on resistance is probably indirect. By profoundly influencing the relative importance of individual species, each with its own inherent resistance, environmental factors exert considerable control on the resistance of the entire community. This is reflected in differences in the resistance of each habitat type.

Table 7—Trampling intensities species can tolerate and still recover[1]

Species	Recovery period	
	Short-term	Long-term
SHRUBS AND SUBSHRUBS		
Arctostaphylos uva-ursi (kinnikinnick)	VL-L	L
Berberis repens (creeping Oregongrape)	VL-L	H
Chimaphila umbellata (prince's-pine)	L	VL
Linnaea borealis (twinflower)	VL-L	M-VH
Pachistima myrsinites (mountain-lover)	VL-L	VL-L
Spiraea betulifolia (shiny-leaf spirea)	VL-L	M-VH
Symphoricarpos albus (snowberry)	VL	M-VH
Vaccinium caespitosum (dwarf huckleberry)	VL	-
Vaccinium globulare (globe huckleberry)	VL	VL
Vaccinium scoparium (grouse whortleberry)	VL	L
GRAMINOIDS		
Calamagrostis rubescens (pinegrass)	VL-L	VL-L
Carex concinnoides (northwest sedge)	L	VL
Festuca scabrella (rough fescue)	M	M
FORBS		
Achillea millefolium (common yarrow)	VH	H
Adenocaulon bicolor (pathfinder)	L	H
Antennaria racemosa (raceme pussy-toes)	VL	L
Arenaria congesta (capitate sandwort)	M	VH
Arnica cordifolia/A. latifolia (heart-leaf/mountain arnica)	M-H	H
Aster conspicuus (showy aster)	L	L-H
Chrysopsis villosa (hairy golden-aster)	H	M
Clintonia uniflora (queen's cup beadlily)	L	H
Fragaria virginiana (blueleaf strawberry)	VL-L	L
Galium triflorum (fragrant bedstraw)	VL	VH
Geranium viscosissimum (sticky purple geranium)	M	VH
Goodyera oblongifolia (western rattlesnake-plantain)	L	L
Hedysarum occidentale (western sweetvetch)	L	-
Hieracium albiflorum (white-flowered hawkweed)	L	L
Lupinus argenteus (silvery lupine)	L	-
Lupinus sericeus (silky lupine)	VH	VH
Melampyrum lineare (narrow-leaved cow-wheat)	L	M
Osmorhiza chilensis (mountain sweet-root)	L	M-H
Potentilla gracilis (slender cinquefoil)	H	VH
Smilacina stellata (starry false Solomon's seal)	L	L
Solidago missouriensis (Missouri goldenrod)	H	VH
Thalictrum occidentale (western meadowrue)	L	VL-L
Viola orbiculata (round-leaved violet)	L	M
Xerophyllum tenax (beargrass)	M-H	L
TREE SEEDLINGS	VL	VL
MOSSES	L-M	H
LICHENS	L	VL

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[1] Species were evaluated on the basis of the maximum number of passes per year for lanes on which relative cover was at least 80 percent either (a) after one season of trampling and one 10-month recovery period (short-term) or (b) after three seasons of trampling and 3 years of recovery (long-term). Classes of trampling intensity were very heavy (VH) (≥1,200 passes); heavy (H) (600-900 passes); moderate (M) (200-400 passes); light (L) (75-100 passes); very light (VL) (≤40 passes).

The primary factor influencing the damage caused by a given level of trampling appeared to be the morphological characteristics of each species. While all species declined in cover as trampling intensity increased, some declined much more than others. The ability of a species to avoid being damaged by trampling appeared to be most strongly related to characteristics of the aerial portion of the plant. This has been noted before by Schreiner (1973) and Rees and Tivy (1978), despite the former's attempt to relate resistance to location of the perennating bud. Location of buds is likely to affect resilience and even the ability to survive repeated trampling, but there is little reason to expect it to affect the ability to survive one season of trampling.

The characteristics that have the greatest influence on resistance appear to be the woodiness, flexibility, erectness, height, and density of stems, and the location, size, and strength of leaves. Most woody shrubs and subshrubs are moderately resistant (table 6). The more resistant of these are large (such as *Amelanchier alnifolia*), have stout stems and branches (such as *Berberis repens*), or have flexible stems that creep along the ground (such as *Arctostaphylos uva-ursi* [kinnikinnick]). Woody species that are erect, with stems and branches that are not stout (such as *Spiraea betulifolia*) or are brittle (such as *Vaccinium globulare*) are more sensitive. Woodiness precludes a species from being resistant, but it gives the plant enough strength so that it is not likely to be highly sensitive.

Responses of herbaceous species are more divergent. All of the species with high and very high resistance had densely clustered stems and/or basal leaves that form resistant and persistent mats or tufts. These include both dicotyledonous species with flexible stems projecting from a woody caudex and monocotyledonous species with dense clusters of basal leaves. The very most resistant of these also have leaves that are tough and either small (such as *Arenaria congesta*) or long and thin (such as *Festuca scabrella* and *Xerophyllum tenax*). All of the herbs that did not grow in dense clusters were quite sensitive to trampling. For these species, sensitivity increased with increasing plant height and leaf/stem ratio.

As has been reported in most other studies, mosses were quite resistant to at least moderate levels of trampling while lichens were quite sensitive; neither exhibited an extreme response. The resistance of mosses was particularly pronounced where they formed a thick mat. This mat was compressed by trampling but it acted as a springy cushion that absorbed much of the trampling pressure. A thin layer of mosses growing on rock would probably have been more easily abraded and been much more sensitive. Lichens tended to break rather than compress and, therefore, were readily damaged by trampling.

In contrast to resistance, the resilience of individual species **did** differ between habitat types; this suggests that resilience is influenced substantially by environmental factors. Plants growing on the ABLA/CLUN plots, in particular, recovered much more than individuals of the same species on other habitat types. The cause of this greater resilience was not determined, but ABLA/CLUN is generally the most productive of the forested types (Pfister and others 1977). Soil fertility and moisture and a long growing season could also have contributed.

Although environmental factors strongly influence resilience, characteristics of the plants themselves remain important as well. Position of the perennating bud and physiological characteristics such as reproductive capacity and growth rates become extremely important. Short-term resilience is low in most of the shrubs (table 6) that have perennating buds above the ground surface where they can be injured by trampling. Shrubs that can sprout vigorously from rhizomes (such as *Spiraea betulifolia* and *Symphoricarpos albus*) can grow back quickly, however. Given a reprieve from trampling, most shrubs grow slowly but steadily.

The most resilient species are herbaceous ones that die back every winter to perennating buds located at or beneath the ground surface. Growth can be either from a rhizome (such as *Arnica cordifolia*) or a caudex (such as *Osmorhiza chilensis*). Growth tended to be less in species with aerial parts that persist from year to year (such as *Festuca scabrella* and *Xerophyllum tenax*) and species with perennating organs that were not tough enough to survive heavy trampling (such as *Calamagrostis rubescens*). Several rhizomatous species were highly resilient after the first trampling dosage (fig. 17), but successive years of trampling diminished this resilience (for example, *Clintonia uniflora*, *Smilacina stellata*, and *Thalictrum occidentale*). Either the rhizomes were increasingly injured after each year, or loss of photosynthetic tissues every year eventually diminished carbohydrate reserves to the point where resprouting could not occur. The one widespread annual on these plots, *Melampyrum lineare* (narrow-leaved cow-wheat), proved to be highly resilient, having little problem reproducing by seed even on quite severely trampled lanes.

One interesting conclusion is that few species were both highly resistant and resilient; similarly, few have both low resistance and resilience. The species that can resist trampling are those with tough aerial parts that develop over several growing seasons. Once destroyed, it takes several years for these parts to grow back. The species that can grow rapidly enough to cover a trampled site tend to have aerial parts that are flimsy and spreading and, therefore, unable to resist trampling.

In sum, shrubs generally had moderate resistance, low short-term resilience, and variable long-term resilience. Several of the less resistant shrubs were quite resilient. Graminoids varied greatly in resistance and long-term resilience; all had low short-term resilience. The more resistant species were also most resilient. Forbs were also variable in response. The most common response is to have low resistance and high resilience. Several species had high short-term resilience but low long-term resilience, and several of the more resistant species were not highly resilient. Tree seedlings were not very resistant and they had low resilience; once irreparably damaged they must reproduce from seed. Mosses were quite resistant and moderately resilient, while lichens were neither resistant nor resilient.

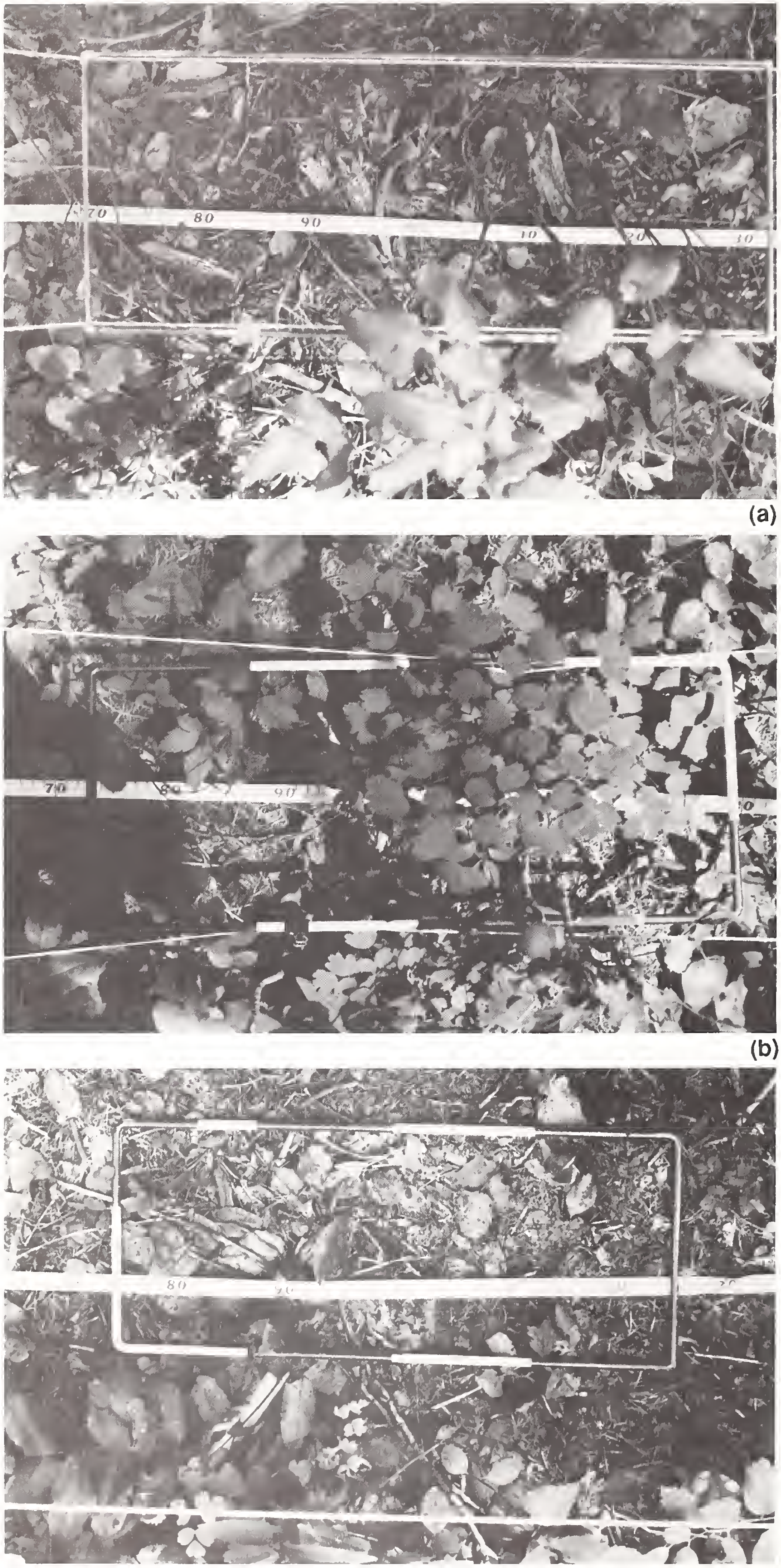
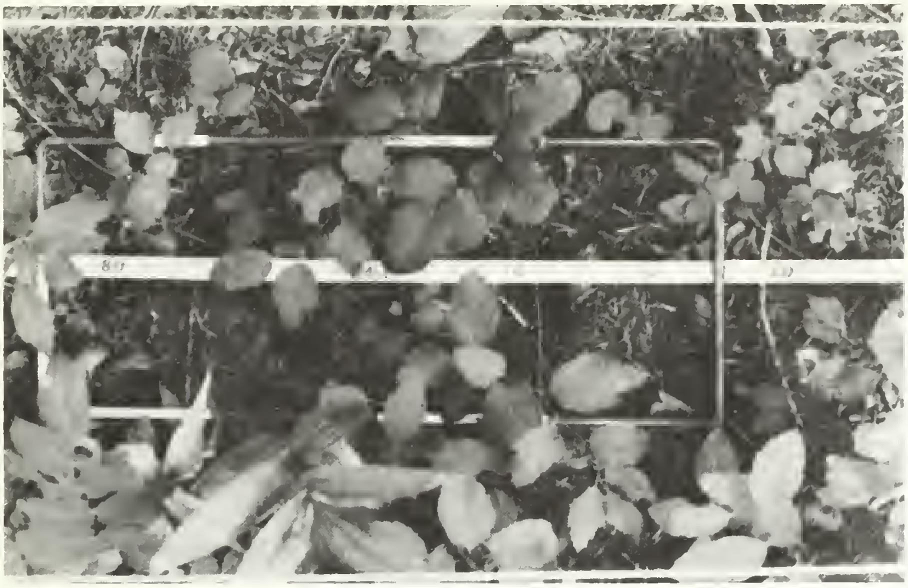


Figure 17—A subplot in lane with 200 passes per year of the *Abies lasiocarpa/Clintonia uniflora* habitat type in (a) August 1981 (after the first season of trampling), (b) June 1982 (after the first overwinter recovery period), (c) August 1983 (after the third season of trampling), and (d) June 1984 (after the third overwinter recovery period). Species cover was 22 percent after the first trampling season (a) and only 7 percent after the third (c). Species cover was 91 percent after the first recovery period (b) and 57 percent after the third (d). *Berberis repens* provided a constant 15-percent cover, except immediately after the third season of trampling (c). *Thalictrum occidentale*, the dominant before trampling, recovered from the first season of trampling (35 percent cover in b), but not from the third (1 percent cover in d).



(d)

Fig. 17 (Con.)

RESPONSES OF SOIL ORGANIC HORIZONS

Deterioration

Response of the soil organic horizon was examined by measuring increases in exposed mineral soil that occurred when overlying organic horizons were removed by trampling and erosion. By August 1983, three successive summers of trampling had exposed mineral soil in all but one of the habitat types, ABLA/CLUN (table 8). Exposure increased as trampling intensity increased; however, in contrast to vegetation loss, the relationship between exposure and trampling intensity was linear (fig. 18). Compared to vegetation loss, much higher trampling intensities are required to expose a substantial amount of mineral soil.

Large standard errors in figure 18 indicate high variability. Some of this is local variability between subplots in the same habitat type, but much of it reflects large differences among types. Differences among types are most pronounced at the highest trampling intensities (another contrast to the response of vegetation).

A final contrast to vegetational response is provided by the response of exposure to successive years of trampling. Exposure increased after each successive year of trampling (fig. 19), particularly on the lanes that received the heaviest trampling; vegetation was generally not affected further by the third season of trampling. Loss of organic horizons and exposure of mineral soil is an impact that may worsen with continued trampling, without reaching an equilibrium level (at least within 3 years).

Recovery

Mineral soil exposure decreased rapidly after trampling was curtailed. Even the lanes trampled 1,600 times per year had a mean exposure of less than 1 percent after 3 years without trampling (table 9). Only the lane with 900 passes per year in ABLA/XETE had more than 3 percent exposure 3 years after trampling ceased.

Recovery was rapid on all habitat types (fig. 20). In the three forested types that experienced the least exposure following trampling, ABLA/CLUN, ABLA/CLUN-VACA, and PSME/SYAL, organic horizons covered the entire soil surface. ABLA/XETE, the type that experienced the most exposure, had recovered greatly, but some mineral soil was exposed on the most heavily trampled lanes. The FESC-FEID grassland, however, recovered more slowly. Median exposure on the most heavily trampled lanes was still 2.5 percent after 3 years of recovery. Even here, however, recovery of a complete litter cover should require only about 5 years.

Table 8—Increase[1] in mineral soil exposure after three seasons of trampling

Number of passes per year	ABLA/ XETE	PSME/ SYAL	FESC- FEID	ABLA/ CLUN-VACA	ABLA/ VACA	ABLA/ CLUN	All habitat types
	Percent						
0	0	0	0	0	0	0	0
5	0	0	+	0	0	0	+
15	0	0	0	0	0	0	0
25	0	0	1	0	0	0	+
40	0	0	0	0	0	0	0
75	2	2	1	0	0	0	1
80	1	3	1	0	0	0	1
100	3	1	1	0	+	0	1
200	2	1	+	1	1	0	1
300	7^{b}	3^{ab}	1^{a}	$+^{a}$	1^{a}	0^{a}	2
400	6	2	+	3	2	0	2
600	9	10	2	1	1	0	4
800	8	6	3	1	1	0	4
900	16	7	6	4	3	0	7
1,200	11^{ab}	14^{ab}	11^{ab}	26^{b}	2^{a}	0^{a}	10
1,600	22	11	17	8	2	0	11
Mean of all treatments	5	4	3	3	1	0	3

[1] Increase is the difference in percentage of mineral soil exposed before and after trampling. Any two values in the same row followed by the same letter are not significantly different (Duncan's multiple range test, $p = 0.05$). Rows with no letters have no significant differences. + indicates <0.5 percent exposure.

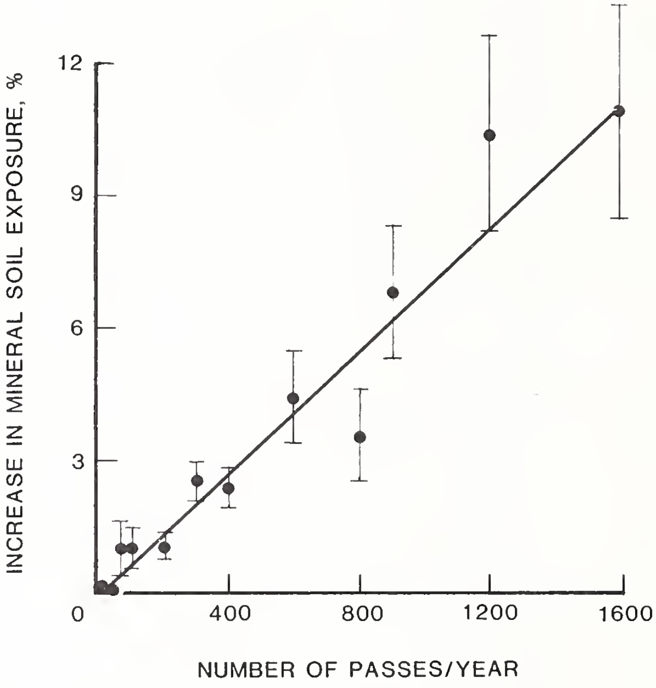


Figure 18—Relationship between trampling intensity and increase in mineral soil exposure after three seasons of trampling. Increase is the difference in percent mineral soil exposure before and after trampling. Data are the mean of all habitat types. Vertical bars are ±1 standard error.

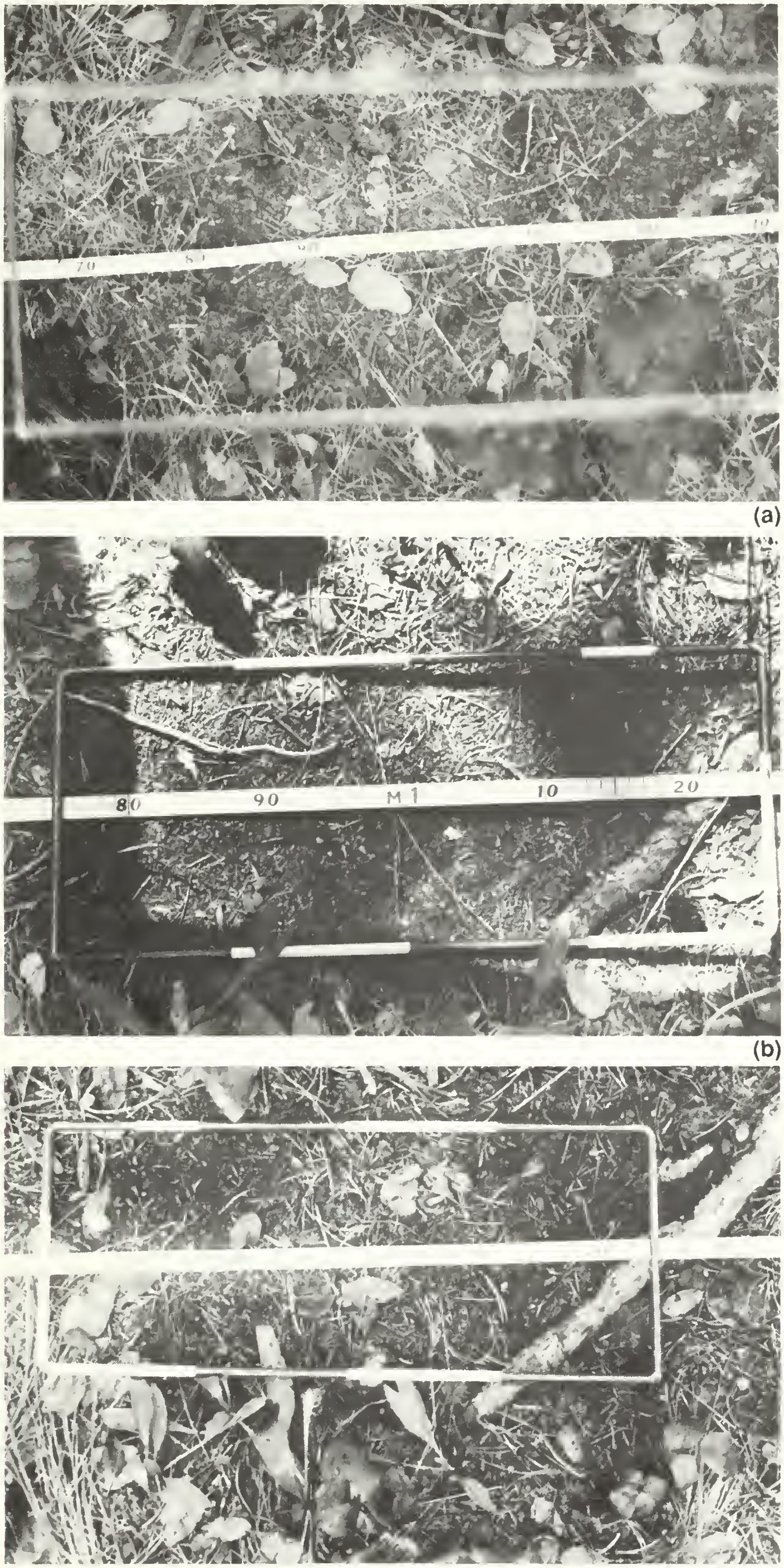


Figure 19—Progressive erosion of organic material and exposure of mineral soil on a subplot receiving 600 passes per year in the *Pseudotsuga menziesii/ Symphoricarpos albus* habitat type after one (a), two (b), and three (c) seasons of trampling.

Table 9—Increase[1] in mineral soil exposure 3 years after trampling ceased

Number of passes per year	Habitat type					All habitat types
	ABLA/ XETE	FESC- FEID	PSME/ SYAL	ABLA/ CLUN-VACA	ABLA/ CLUN	
	Percent					
0	0	0	0	0	0	0
5	0	0	0	0	0	0
15	0	0	0	0	0	0
25	0	0	0	0	0	0
40	0	0	0	0	0	0
75	+	+	0	0	0	+
80	+	0	0	0	0	0
100	0	0	0	0	0	0
200	1	0	0	0	0	+
300	0	0	0	0	0	0
400	1	0	0	0	0	+
600	1	0	+	0	0	+
800	1	1	1	0	0	1
900	5	1	0	0	0	1
1,200	+	3	+	1	0	1
1,600	1	3	0	0	0	1
Mean of all treatments	0.6	0.4	0.1	0.1	0	0.3

[1] Increase is the difference in percentage of mineral soil exposed before trampling and after trampling and recovery. No differences among habitat types were statistically significant (Duncan's multiple range test, $p = 0.05$). + indicates <0.5 percent exposure.

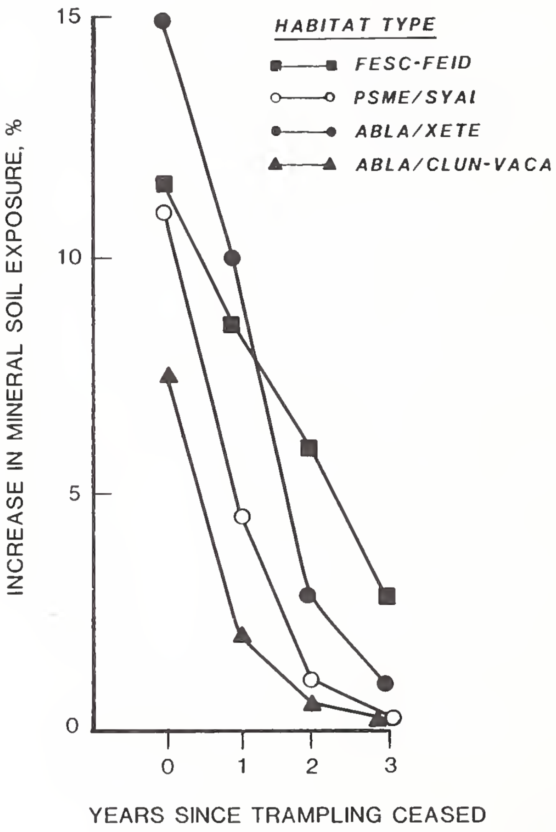


Figure 20—Differences among habitat types in recovery of organic horizons following the cessation of trampling. Increase in mineral soil exposure is the difference in percentage of mineral soil exposed before trampling and at some later date. Data are for heavy trampling intensities (median of 900, 1,200, and 1,600 passes per year). ABLA/CLUN had no soil exposure. Standard error ranges were 2.1 to 6.0 percent (year 0), 2.5 to 3.9 percent (year 1), 0.7 to 3.2 percent (year 2), and 0 to 1.8 percent (year 3).

The reader should note that the definition of recovery is two-dimensional, based entirely on surficial cover. Organic horizon depth was not measured, so it is not possible to draw any conclusions about loss or recovery of volume, weight, or depth of organic matter. It seems intuitively obvious that a reduction in depth and volume would occur more rapidly than an increase in area of mineral soil—much as species cover decreased more rapidly than vegetation cover. For example, the thick organic horizons on the ABLA/CLUN type were entrenched on the heavily trampled lanes, despite the lack of mineral soil exposure. It also seems obvious that recovery of the original depth and volume of organic matter would require a longer period of time than recovery of a complete surficial cover. Although exposure of mineral soil occurs more slowly than loss of vegetation and recovery occurs more rapidly, this does not necessarily mean that impact to organic horizons occurs more slowly and recovery is more rapid.

What Determines Amount of Deterioration and Recovery?

Both of the controlled variables, trampling intensity and habitat type, had a profound influence on amount of deterioration. Maximum exposure occurred on habitat types that had thin organic horizons initially or that were located on sloping sites. ABLA/CLUN had a mean organic horizon thickness of more than 4 inches (11 cm) and never experienced any soil exposure. ABLA/XETE, which experienced the most pronounced exposure, had a mean organic horizon thickness of only 0.25 inch (0.7 cm). PSME/SYAL experienced high exposure, despite having organic horizons that averaged more than 2 inches (6 cm) in depth. These plots were located on a 20 to 25 percent slope, however; this promoted downslope movement of material disturbed by trampling (despite the fact that lanes paralleled contours).

There was a linear relationship between mineral soil exposure and trampling intensity on all habitat types. On ABLA/CLUN no exposure occurred on any lane. In the other types the linear relationship was positive, with the slope of regression lines increasing from the more-resistant types (ABLA/VACA and ABLA/CLUN-VACA) to the less-resistant types (ABLA/XETE and PSME/SYAL).

Amount of recovery (decrease in mineral soil exposure) is most strongly influenced by trampling intensity (fig. 21). The rate and amount of recovery increases as trampling intensity increases. Those sites that experienced the most exposure also recovered the most. Litter fall on all of these habitat types is sufficient to cover the entire ground surface, regardless of exposure level, within 3 to 5 years.

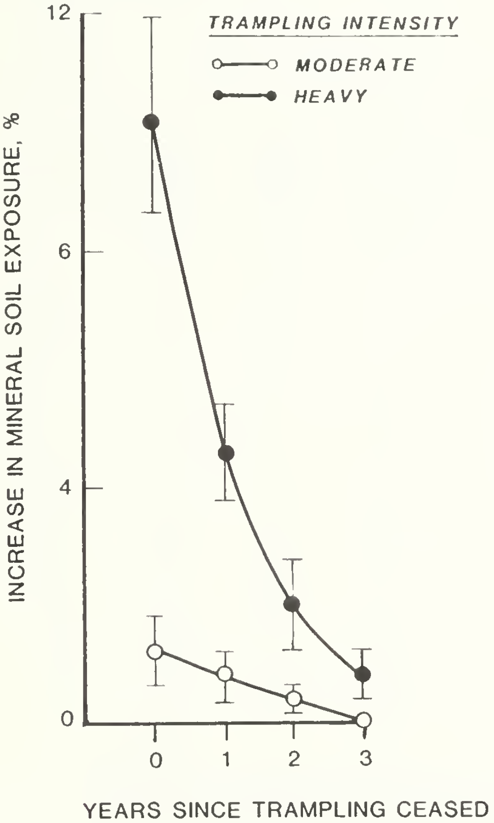


Figure 21—Recovery of organic soil horizons following cessation of heavy trampling (median of 900, 1,200, and 1,600 passes per year) and moderate trampling (median of 100, 200, and 300 passes per year). Increase in mineral soil exposure is the difference in percentage of mineral soil exposed before trampling and at some later date. Data are the mean of all habitat types. Vertical bars are ±1 standard error.

COMPACTION AND RECOVERY OF THE MINERAL SOIL

Deterioration

By August 1983, three successive summers of trampling had compacted the mineral soil, increasing the soil's resistance to penetration. Penetration resistance increased as trampling intensity increased (table 10). The relationship between trampling intensity and increase in penetration resistance was asymptotic rather than linear (fig. 22). The second season of trampling resulted in higher levels of compaction than the first season, but the third trampling season had no additional effect. In regards to the nature of the relationship to trampling intensity and the effects of successive trampling seasons, the response of penetration resistance is more similar to that of vegetation cover than of exposure of mineral soil.

Differences among habitat types in the severity of compaction were pronounced, particularly at trampling intensities of 400 to 900 passes per year (table 10). Types with thick organic horizons and little mineral soil exposure following trampling usually experienced the least compaction. Soil compaction was least severe in ABLA/CLUN and most severe on the ABLA/VACA, PSME/SYAL, and ABLA/XETE types. Organic horizons cushion the underlying mineral soil from the pressures of trampling, reducing compaction.

Recovery

Penetration resistance decreased after trampling was curtailed, indicating recovery from compaction. For all habitat types and trampling intensities, mean resistance decreased from 2.2 tons/ft^2 (2.2 kg/cm^2) immediately after three seasons of trampling to 1.8 tons/ft^2 (1.8 kg/cm^2), 1.8 tons/ft^2 (1.8 kg/cm^2), and 1.3 tons/ft^2 (1.3 kg/cm^2), after the first, second, and third year of recovery. Mean resistance on controls varied between 0.6 and 0.8 ton/ft^2 (0.6 and 0.8 kg/cm^2). The apparent lack of recovery during the second year of recovery reflected abnormally dry soils following a season of drought. Penetration resistance tends to increase as soil moisture decreases, even if soil compaction remains constant.

Although compaction levels have decreased steadily, compaction was still high after 3 years of recovery. Three years after trampling ceased, the penetration resistance of the lanes with 1,600 passes per year was still almost three times higher than that on controls. Only in the FESC-FEID type did several of the trampled lanes have resistances as low as controls (table 11).

Recovery rates varied between habitat types (fig. 23). Least recovery occurred in ABLA/CLUN, the type that experienced the least compaction. PSME/SYAL and FESC-FEID recovered the most. Because FESC-FEID recovered greatly after experiencing only moderate compaction, it had the highest level of recovery (penetration resistance

Table 10—Increase[1] in soil penetration resistance after three seasons of trampling

Number of passes per year	Habitat type						All habitat types
	ABLA/ VACA	PSME/ SYAL	ABLA/ XETE	ABLA/ CLUN-VACA	FESC-FEID	ABLA/ CLUN	
	kg/cm^2						
0	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0
5	0.2^{a}	0.2^{a}	0.2^{a}	0.2^{a}	0.2^{a}	0.3^{a}	0.2
15	.5^{a}	.3^{a}	.7^{a}	.4^{a}	.4^{a}	.3^{a}	.4
25	.6^{a}	.3^{a}	.7^{a}	.4^{a}	.5^{a}	.2^{a}	.5
40	.7^{a}	.4^{a}	.6^{a}	1.1^{a}	.7^{a}	.3^{a}	.6
75	1.1^{a}	.8^{a}	1.0^{a}	.8^{a}	.4^{a}	.4^{a}	.8
80	1.7^{b}	.9^{a}	2.0^{b}	.7^{a}	.8^{a}	.6^{a}	1.2
100	1.4^{a}	1.1^{a}	1.5^{a}	.7^{a}	1.0^{a}	.5^{a}	1.1
200	1.8^{a}	1.6^{a}	1.7^{a}	1.2^{a}	1.3^{a}	1.0^{a}	1.5
300	2.6^{c}	2.4^{c}	2.4^{c}	1.6^{b}	1.2^{ab}	1.0^{a}	2.0
400	3.5^{d}	2.4^{bc}	2.6^{bc}	2.6^{bc}	1.8^{ab}	1.2^{a}	2.4
600	3.2^{d}	3.0^{d}	2.8^{cd}	1.8^{b}	2.2^{bc}	.9^{a}	2.5
800	3.8^{b}	2.7^{a}	2.3^{a}	2.1^{a}	2.3^{a}	1.9^{a}	2.6
900	3.3^{c}	2.6^{bc}	2.6^{bc}	2.7^{bc}	1.8^{b}	1.2^{a}	2.5
1,200	3.3^{bc}	3.8^{c}	2.7^{b}	3.2^{bc}	2.0^{a}	1.9^{a}	2.9
1,600	3.5^{c}	3.5^{c}	3.1^{bc}	2.6^{ab}	2.7^{ab}	2.3^{a}	3.1
Mean of all treatments	2.0^{d}	1.7^{c}	1.7^{cd}	1.4^{bc}	1.2^{ab}	.9^{a}	1.5

[1] Increase is the difference in penetration resistance between control and treatment plots. Any two values in the same row followed by the same letter are not significantly different (Duncan's multiple range test, $p = 0.05$).

3 years after trampling ceased was lowest). Other types were intermediate in response. Estimates of how long it would take for the penetration resistance of the most heavily trampled lanes to recover to within 10 percent of that on undisturbed controls range from 5 to 6 years in FESC-FEID to about 12 to 15 years in ABLA/XETE, PSME/SYAL, and ABLA/CLUN-VACA.

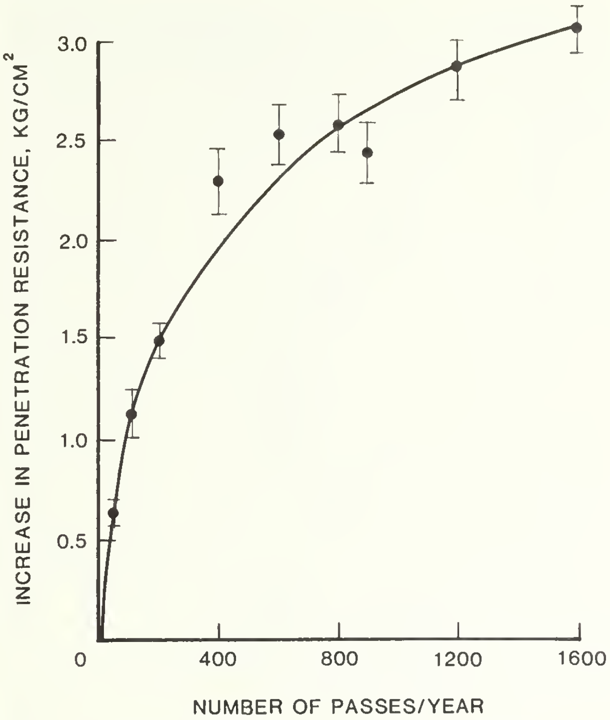


Figure 22—Relationship between trampling intensity and increase in penetration resistance. Increase is the difference in penetration resistance between control and treatments. Data are the mean of all habitat types. Vertical bars are ±1 standard error.

What Determines Amount of Deterioration and Recovery?

Both of the controlled variables, trampling intensity and habitat type, influenced amount of soil compaction (deterioration). Compaction was generally less severe on sites that retained thick organic horizons after trampling. Compaction on lanes with 600 passes per year in ABLA/CLUN, which experienced no exposure of mineral soil, was less than one-third of that in types that experienced substantial soil exposure. Compaction also increased with trampling intensity, both because the pressures exerted increase with trampling intensity and because organic horizons are thinner and less complete where trampling intensity is high. Nevertheless, amount of compaction does level off at high trampling intensities, despite linear increases in soil exposure at heavy trampling intensities.

Amount of recovery is most strongly influenced by trampling intensity (fig. 24). The rate and amount of recovery increases as trampling intensity increases.

Table 11—Increase[1] in penetration resistance 3 years after trampling ceased

Number of passes per year	Habitat type					All habitat types
	ABLA/ XETE	ABLA/ CLUN-VACA	PSME/ SYAL	ABLA/ CLUN	FESC- FEID	
	kg/cm^2					
0	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0
5	0.3^{b}	0.2^{ab}	0^{a}	0^{a}	0^{a}	0.1
15	.4^{b}	.4^{b}	0^{ab}	0.3^{b}	−0.1^{a}	.1
25	.6^{b}	.2^{ab}	0.1^{ab}	.1^{ab}	0^{a}	.2
40	.2^{a}	.3^{a}	.3^{a}	.4^{a}	.1^{a}	.2
75	.4^{b}	.4^{b}	0^{a}	.3^{b}	−.2^{a}	.1
80	.4^{b}	.2^{b}	.4^{b}	.3^{b}	−.1^{a}	.3
100	.6^{b}	.6^{b}	.3^{ab}	.3^{ab}	0^{a}	.3
200	.6^{b}	1.0^{b}	.6^{b}	.5^{b}	−.1^{a}	.4
300	1.1^{b}	.9^{b}	.8^{b}	.7^{b}	.1^{a}	.7
400	.9^{b}	.9^{b}	.8^{b}	.9^{b}	.4^{a}	.7
600	1.3^{b}	1.2^{b}	1.0^{b}	1.0^{b}	.4^{a}	1.0
800	1.0^{bc}	1.6^{c}	.9^{b}	1.0^{bc}	.5^{a}	.9
900	1.3^{c}	1.1^{bc}	.9^{bc}	.7^{b}	.3^{a}	.8
1,200	1.7^{b}	1.2^{b}	1.4^{b}	1.1^{b}	.4^{a}	1.3
1,600	1.7^{bc}	2.2^{c}	1.3^{bc}	1.1^{b}	.4^{a}	1.3
Mean of all treatments	.8^{c}	.8^{bc}	.6^{b}	.5^{b}	.1^{a}	.5

[1] Increase is the difference in penetration resistance between control and treatment plots. Any two values in the same row followed by the same letter are not significantly different (Duncan's multiple range test, $p = 0.05$).

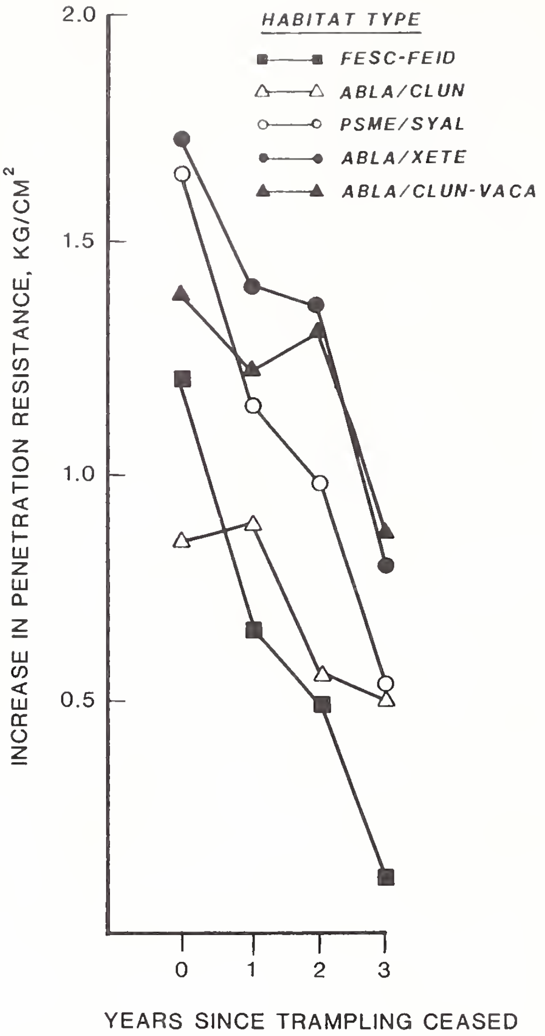


Figure 23—Differences among habitat types in recovery of compacted soils following the cessation of trampling. Increase is the difference in penetration resistance between control and treatments. Data are the mean of all trampling intensities. All standard errors were 0.13 kg/cm² or less.

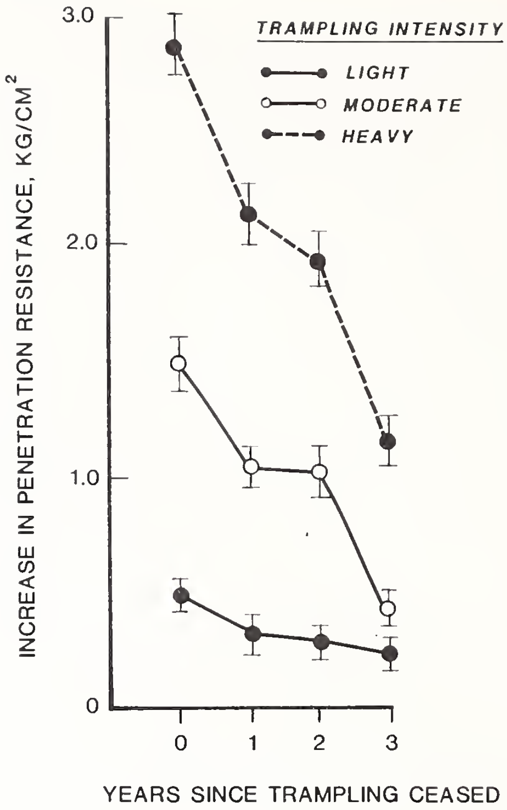


Figure 24—Recovery of compacted mineral soil following cessation of trampling at light (median of 15, 25, and 40 passes per year), moderate (100, 200, and 300 passes per year), and heavy (median of 900, 1,200, and 1,600 passes per year) intensities. Increase is the difference in penetration resistance between control and treatments. Data are the mean of all habitat types. Vertical bars are ±1 standard error.

Those sites that experienced the most compaction generally recovered the most. There is no evidence to suggest that there is a threshold beyond which the ability to recover declines. This response is similar to that of the organic horizon and contrasts with the response of vegetation.

MANAGEMENT IMPLICATIONS

The results of these experiments can be used to predict the effects of cross-country hiking and of trampling on campsites; the difficulty lies in correlating these treatments with recreational use. The impacts associated with a given number of passes per year would be the same as those caused by a comparable number of hikers, if they walked single file. Where hikers spread out, prediction is less precise. The effect of a given number of hikers can be approximated by dividing the number of hikers by a factor (related to how much hikers spread out) and looking up the effects of that many passes per year. For example, if 300 people per year follow a route that allows a moderate amount of spreading out, perhaps only one-third of the hikers follow the same route. In this case, the effects of 300 people per year would approximate those observed on the lane with 100 passes per year. While this need to compensate for hikers spreading out interjects a source of inaccuracy, the results of these experiments improve the ability to predict the effects of cross-country hikers. Results cannot be readily applied to hikers on trails because constructed trails are so different from undisturbed environments.

The effects of trampling on campsites can also be predicted. Many campsite impacts (for example, tree damage and fire building) are unrelated, but most of the loss of vegetation and organic matter and the compaction of soils on campsites results from trampling roughly comparable to that administered in these experiments. These impacts can be predicted. Observations and limited experimentation (Cole 1985, 1987a) indicate that the trampling impacts caused by a typical party of two to three people, in one night of camping, are similar to those caused by 75 to 150 experimental passes. This would apply to the central portion of the campsite, where use is heaviest.

These correlations allow us to estimate how much camping and hiking different sites can tolerate before deteriorating to unacceptable levels. The predictions should be treated as rough estimates, subject to several sources of inaccuracy. The translation from number of passes to nights of camping and number of hikers is rough. Moreover, recovery levels are overestimated because trampling occurred for only 3 years and vegetation could spread from little-disturbed buffer strips a short distance away. Finally, it is not clear how site-specific results are. Mineral soil exposure definitely would have been more pronounced if plots had been on slopes rather than on flat topography. This is important to remember when using these results to predict the effects of cross-country hikers.

In the following section the likely effects of various numbers of hikers walking single-file and of nights of camping will be described for the three habitat types with the most divergent responses—FESC-FEID, ABLA/CLUN, and ABLA/XETE. Likely responses of the ABLA/VACA, PSME/SYAL, and ABLA/CLUN-VACA types will usually fall between those of the ABLA/CLUN and ABLA/XETE types.

The FESC-FEID Habitat Type

One Hundred Hikers; One Night of Camping—A previously undisturbed site crossed by 100 hikers or camped on for one night is likely to experience some flattening of vegetation and short-term loss of forbs, but vegetational cover remains complete, no mineral soil is exposed, and soil compaction is minimal. Recovery of vegetation is complete by the following year.

One Hundred Hikers per Year; One Night of Camping per Year—Continuation of this level of use will cause slight vegetation loss, soil exposure, and soil compaction. The only visual evidence to users will be flattening of the vegetation, although complete recovery will take several years.

Five Hundred Hikers per Year; Five Nights of Camping per Year—This will result in loss of about 50 percent of the vegetation cover, slight exposure of mineral soil, and substantial soil compaction. If use is curtailed, vegetational cover and litter cover may be completely restored within 3 years, but some cover loss and soil compaction remain.

One Thousand to 1,500 Hikers per Year; 10 to 15 Nights of Camping per Year—This will eliminate most, but not all, vegetational cover; resistant clumps of *Festuca scabrella* survive. Mineral soil exposure exceeds 10 percent and soils are highly compacted. One year after use is curtailed, vegetational cover will exceed 50 percent and soil compaction will have been reduced substantially, but soil exposure remains high. Most visual evidence of use should disappear within 3 years. (Remember that recovery may be less rapid where use has occurred for more than 3 years.)

The ABLA/CLUN Habitat Type

One Hundred Hikers; One Night of Camping—This will eliminate most of the vegetation, but no mineral soil will be exposed and soil compaction will be negligible. Most visual evidence of impact will disappear in 1 year, although a number of species will have reduced cover.

One Hundred Hikers per Year; One Night of Camping per Year—This will eliminate most of the vegetation, but no mineral soil is exposed and soil compaction is low. Vegetational cover will exceed 50 percent 1 year after use is curtailed and will appear undisturbed after 3 years of recovery, although complete recovery of all species has not occurred.

Five Hundred Hikers per Year; Five Nights of Camping per Year—Only a few vegetation remnants survive. Although there is still no mineral soil exposure, substantial soil compaction occurs. Vegetational cover will be about 50 percent 1 year after use is curtailed, but little reduction in compaction occurs. After 3 years of recovery, vegetational cover is nearly complete, although some loss is still evident and soil compaction is still substantial.

One Thousand to 1,500 Hikers per Year; 10 to 15 Nights of Camping per Year—All vegetation is eliminated and soil compaction is moderately high, although no mineral soil is exposed. Little recovery occurs in 1 year. After 3 years of recovery most of the site is covered with vegetation, although it is noticeably sparse and a path is still evident. Compaction levels have moderated but are still substantial. (Again, recovery may be less rapid where use has occurred for more than 3 years.)

The ABLA/XETE Habitat Type

One Hundred Hikers; One Night of Camping—Loss of vegetation and a path are evident, although most of the site remains vegetated. Some mineral soil is exposed and substantial compaction occurs. Little vegetational recovery occurs in 1 year, although compaction levels are reduced.

One Hundred Hikers per Year; One Night of Camping per Year—About one-half of the vegetation is lost, some mineral soil is exposed, and soil compaction is moderately high. One year after use is curtailed, the only pronounced change is a reduction in compaction. After 3 years of recovery, little visual evidence of disturbance remains, although compaction levels are still elevated and some species have not regained complete cover.

Five Hundred Hikers per Year; Five Nights of Camping per Year—Most, but not all, vegetation is eliminated, mineral soil exposure exceeds 5 percent and is visually evident, and soil compaction is high. Little recovery occurs in one season. After 3 years of recovery, most of the path/site is vegetated, although vegetation is noticeably sparse. Litter cover is nearly complete, but compaction levels remain substantial.

One Thousand to 1,500 Hikers per Year; 10 to 15 Nights of Camping per Year—Most, but not all, vegetation is lost, mineral soil is widespread (about 15 to 20 percent), and soil compaction is severe. Aside from a sizable decrease in mineral soil exposure, little recovery occurs in 1 year. After 3 years of recovery, a sparse vegetation covers about 50 percent of the path/site, litter cover is nearly complete, and soil compaction is still moderately high. (Again, recovery may be less rapid where use has occurred for more than 3 years.)

One obvious conclusion is how little use these sites can sustain and still recover in one growing season. Only the FESC-FEID grassland can tolerate one night of camping per year without experiencing deterioration from which it cannot recover in 1 year; it can tolerate three to four nights per year. Therefore, if managers are attempting to keep vegetation damage to a level where it can recover in a year (this is a frequently mentioned objective in remote, relatively undisturbed portions of wilderness), they should convince people to camp on grasslands rather than in the forests. Even grassland sites should not be used if damage is apparent, and use levels must be low enough so that no site is used more than a few times per year. Cross-country hikers should also be encouraged to walk through grassland rather than forest. While hundreds of hikers per year can cross grasslands and have no long-term effect, as few as 20 to 25 hikers per year, if they walk single-file, can damage the vegetation of the forested habitat types to the point where recovery is not complete in one season. In areas where hikers cannot avoid forest vegetation and managers want to avoid creation of new trails, use levels must be low enough so that no more than 20 to 25 hikers per year are likely to follow the same route. If hikers spread out rather than walk single-file, areas can accommodate more use before impacts become noticeable.

Where use is heavy and long-term vegetation damage is inevitable, managers might want to limit use to levels where mineral soil exposure will not be substantial—for example, where soil exposure is confined to less than 5 percent of the concentrated-use part of the site. The maximum number of passes per year that caused no more than a 5 percent increase in mineral soil exposure was 1,600 in ABLA/CLUN and ABLA/VACA, 900 in ABLA/CLUN-VACA, 800 in FESC-FEID, 400 in PSME/SYAL, and 200 in ABLA/XETE. ABLA/CLUN and ABLA/VACA are clearly the most durable locations; they can tolerate a week or two of camping per year or be walked on by over 1,000 hikers per year (provided there is no slope, as was the case in these experiments). Even one night of camping or several hundred hikers is likely to expose mineral soil in the ABLA/XETE type, however.

As has been found in many other studies, these results provide dramatic evidence of the inevitability of impact, particularly to vegetation, wherever people regularly go. This highlights the difficulty of controlling impact through use limitation, as well as the need to concentrate use, in frequently used areas, so that the number of impacted places is limited. Data from this study can be useful in identifying use levels above which concentration is necessary and below which dispersal of use over many sites is feasible as a means of reducing impact. The asymptotic nature of most use/impact relationships permits the identification of use thresholds, located at the trampling intensity where the curves describing these relationships first approach the asymptote. Above these thresholds, use limitation has little effect, amount of impact is not strongly influenced by trampling intensity, and concentration of use is necessary to control impact. Below these thresholds, amount of impact **is** strongly influenced by amount of use, and dispersal of use, to minimize trampling intensity on all sites, is desirable.

For example, figure 25 shows a curve describing the relationship between trampling intensity and vegetational cover in the ABLA/CLUN type. The use threshold is somewhere between 200 and 400 passes per year. Above 400 passes per year, increased trampling has little detrimental effect, while reductions in intensity below 200 passes per year have positive benefits. In other words, if use levels on sites in ABLA/CLUN can be kept below 200 passes per year (about one night of camping per year or the passage of several hundred hikers, walking single-file) it would be valuable to disperse users so that campsites and travel routes are used as infrequently as possible. Campers should select apparently undisturbed sites, and hikers should spread out and avoid trampling the same route. If use is so heavy that sites are likely to be used more than one night per year, either use must be reduced or camping should be concentrated on a few sites. Similarly, if more than several hundred hikers are likely to follow the same route through these forests, trails will develop and it would be best to either construct an "official" trail or reduce use.

Use thresholds vary with impact parameter and habitat type. There were no thresholds for mineral soil exposure because exposure increased linearly with increases in trampling intensity. Use thresholds for the other parameters are presented in table 12. Thresholds are always lowest for vegetation loss. The critical implication of this is that use thresholds for vegetation loss will generally determine whether concentration or dispersal is appropriate. Concentration of camping is best except where use of sites can be kept below seven to eight nights per year in the FESC-FEID grassland, two nights per year in ABLA/XETE, and one night per year in the other forested types. As noted earlier, even these levels of use will cause pronounced impact, so use levels should be as low as possible.

It is almost always best to concentrate use of regularly used places on trails and campsites. Because concentrated use will eliminate even the most resistant vegetation, vegetational resistance is not relevant to the location of concentrated-use campsites. The best locations for such sites, aside from bedrock, are places where organic horizons are thick (for example, in ABLA/CLUN); this will minimize mineral soil exposure and soil compaction. Trail location will be guided by concern for many factors that were not controlled in these experiments, such as soil moisture and erosiveness.

Dispersal is desirable only where use levels can be kept below those defined by use thresholds for vegetation cover (table 12). Even with these use levels, dispersal may cause problems if users do not practice low-impact camping

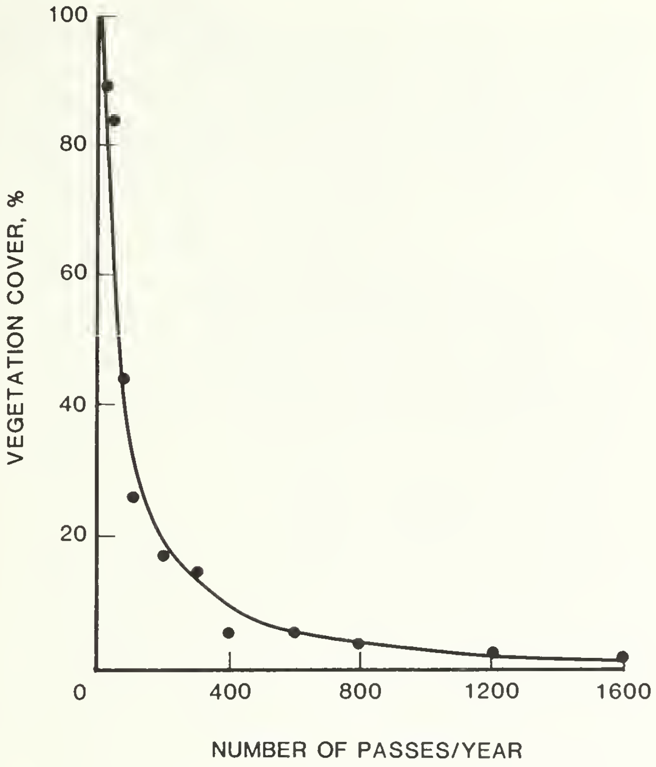


Figure 25—The relationship between vegetational cover and trampling intensity in the *Abies lasiocarpa/ Clintonia uniflora* habitat type after three seasons of trampling. Vegetational cover is the proportion of original cover present after trampling (based on a single estimate of vegetation cover), adjusted for changes on controls.

techniques, so education of users and monitoring of impacts are particularly important. Dispersal should be implemented by convincing people not to camp or hike where previous disturbance is evident. Of vegetated sites, it is best to use grasslands because they can tolerate the most use. The species classifications in tables 6 and 7 can also be used to predict which sites will be most resistant to vegetation loss and, therefore, the best sites for dispersed use. Nonvegetated sites, such as bedrock or beaches, are even better.

These data can also be used to compare deterioration and recovery rates. None of these habitat types could recover completely from any trampling intensity within the period of time over which trampling occurred. This applied to both one season of trampling and recovery and three seasons of trampling and recovery. This provides further evidence that there is little opportunity to minimize impact through alternately opening and closing sites. Rotation of use among a large number of sites will effectively limit impact only where use levels are so low that sites are never allowed to deteriorate substantially. Such a rotation system is identical to the use dispersal strategy discussed previously. Rest-rotation of regularly used and well-impacted sites is not feasible in montane ecosystems such as these, and is even less feasible in less resilient environments such as subalpine ecosystems.

METHODOLOGICAL IMPLICATIONS

This study was the most detailed experimental trampling study that has been conducted. Sources of complexity included varying frequency of trampling (the number of times per season trampling treatments were applied) as well as trampling intensity, the large number of observation times (twice a year for three seasons of trampling and once a year for 3 years of recovery), the number of impact parameters measured, and the number of habitat types studied. This complexity was designed into the study because few of these variables had been adequately examined before. Although much was learned, the study also generated more data than could be readily analyzed and, in hindsight, much of this complexity and detail was unnecessary.

Table 12—Trampling intensities below which reductions in intensity will reduce impact

Habitat type[1]	Impact parameter Vegetation cover	 Species persistence	 Increase in penetration resistance
	Number of passes per year		
GRASSLAND			
FESC-FEID	1,200	>1,600	>1,600
FOREST			
ABLA/XETE	400	1,200	600
PSME/SYAL	200	800	1,200
ABLA/VACA	200	600	400
ABLA/CLUN	200	400	>1,600
ABLA/CLUN-VACA	200	600	1,200

[1] See table 1 for definitions.

The frequency of trampling had no consistent and substantial effect on amount of impact. Bayfield (1979) arrived at the same conclusion. Therefore, it is often valid to apply trampling treatments at one time and assume that the effect is similar to that of the same number of passes spread out over time. This will greatly reduce the time spent trampling. Only when trying to simulate trampling of vegetation in various phenological stages or during very different seasons is frequency of trampling likely to be an important variable.

The range of trampling intensities used was close to ideal, however. Although the highest intensities were not necessary to examine vegetation response, even higher trampling intensities would have been desirable to examine the response of organic horizons.

The examination of a range of habitat types was also useful, particularly in evaluating the magnitude of differences in response. This provided valuable information on how significant differences in site durability were and at what trampling intensities differences were most substantial. An expansion of the range of vegetation types and environmental factors studied seems highly desirable. Perhaps this could be done by independent investigators utilizing a standardized experimental procedure.

The continuation of the experiment over several seasons with many observation times provided some valuable insights. It provided measures of both short- and long-term recovery. It also showed that to simulate continuing recreational use, trampling treatments need to be administered for at least 2 years. Single-season trampling experiments, at least in these habitat types, would have underestimated the impact caused by long-term use, particularly on resistant sites. They would have overestimated differences among sites in susceptibility to vegetation impact and underestimated differences in susceptibility to soil exposure and compaction.

It is my contention, however, that there are more appropriate means of studying the impacts associated with prolonged recreational use and subsequent recovery. In these experiments vegetation recovery occurred more rapidly than it would have on recreation sites because much of the revegetation on trampled lanes spread from adjacent relatively undisturbed buffer strips. Moreover, there was evidence that the ability to recover was diminishing after several seasons of heavy trampling. More than three seasons of trampling may be required before further trampling will have no additional effect on the ability to recover. Closure of existing recreation sites—while replete with its own set of problems—seems to be a more appropriate method for studying recovery of long-used recreation sites.

Prolonged use of almost any site will eliminate most of the vegetation. Therefore, the impacts of most concern where use is prolonged will be soil impacts. These can be usefully studied in an experimental manner, but control and stratification of variables such as soil moisture, soil texture, and slope are usually more important than vegetation type (although vegetation may be correlated with these variables). This calls for either very different types of experiments or studies that monitor changes on recently opened recreation sites.

Experimental trampling of different vegetation types seems most useful in examining the short-term effects and subsequent recovery of relatively light trampling. Differences in vegetation loss among vegetation types are most pronounced at moderately light trampling intensities (100 to 300 passes per year or one to two nights of camping per year) and after just one season of trampling. This type of trampling simulates the effects of various levels of highly dispersed trampling; results can be used to determine appropriate use levels for concentrating or dispersing use.

The most useful aspect of experimental trampling, then, is to study its effects on vegetation, with perhaps four to five incremental increases in number of passes from 0 to 500 or (in resistant vegetation) 1,000 passes. Immediate effects, effects several weeks later (to identify delayed damage), and effects a year later should be measured. Such tests should suffice to identify use thresholds, as well as how much use a site can tolerate and still recover in 1 year. From these data managers can establish use limits that will maintain remote, lightly used areas in essentially pristine condition. They can also inform users of the most durable sites for camping and travel. Other types of information are needed to set use limits or develop other management strategies for more heavily used places where more pronounced impacts are inevitable.

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Cole, David N. 1988. Disturbance and recovery of trampled montane grassland and forests in Montana. Res. Pap. INT-389. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 37 p.

Five forested vegetation types and one grassland in western Montana were subjected to experimental trampling. Changes in vegetational cover, number of species, mineral soil exposure, and soil penetration resistance were examined, as were responses of individual species. Deterioration and recovery following various levels of trampling are described, and factors that influence resistance and resilience are noted. Management implications are discussed.

KEYWORDS: ecological impact, trampling, wilderness, backcountry management, habitat types, damage

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